ENERPUB

User's Manual

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Assistance and Information:

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User Responsibility

Users are responsible for the validity of the information generated by the ENERPUB program. Consequently the program should not be used by those who do not comprehend the technical field to which this program applies. Neither Public Works Canada nor any person acting on behalf of the department makes any warrenty or assumes any responsibility for accuracy, completeness or usefulness of any information generated by this program.

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1. INTRODUCTION

The ENERPUB computer program, developed by Enermodal Engineering Limited for Public Works Canada, can be used to simulate the performance of liquid-based seasonal or short-term storage solar space heating systems with or without a heat pump. The program can also simulate the performance of a solar heating system used to heat oil in oil storage tanks. ENERPUB is not suitable for simulation of solar domestic hot water systems specifically because of the restrictive heat exchanger models.

The ENERPUB program has many advantages over other solar simulation programs. Because performance calculations are made for each simulated hour, the program results are potentially more accurate than those of programs using a monthly calculation procedure, such as FCHART. In addition, the ENERPUB program can simulate a wider range of parameters than programs restricted by monthly average correlation equations. Several of the models in the ENERPUB program were adapted from WATSUN models (WATSUN is an hour-by-hour computer program developed by the University of Waterloo). ENERPUB has several enhancements over the WATSUN space heating programs:

1) Stratified tank model for short term or seasonal storage.
2) Four possible heat pump locations.
3) Inclusion of heat loss from the storage to the building, outdoors or ground.
4) Inclusion of heat loss from collector and storage piping to the building, outdoors or ground.

The ENERPUB computer program gives detailed and accurate results for liquid-based seasonal or short-term storage provided that reasonable values for all system parameters are input. All users should read and understand this manual before using the program.

2. THE ENERPUB COMPUTER PROGRAM

2.1 System Configurations

Figures 1-4 show the four possible space heating systems that can be simulated by the program. The difference between these systems is the manner in which the heat is delivered to the space heating load. Figure 5 shows the oil tank heating system. Note that these systems are all liquid-based; the program cannot handle air-based systems. Piping heat losses can be considered for each of the four regions shown on the figures: collector supply and return, building supply and return. The abbreviations used in the figures are:

CL	- solar collector
ST	- thermal storage tank
OIL	- oil storage tank
AUX	- auxiliary heating system
DHW	- domestic hot water system
HP	- heat pump
HX_C	- collector-storage heat exchanger
HX_W	- storage-DHW heat exchanger
HX_B	- storage-building heat exchanger
P1,P2,P3,P4	- circulation pumps
V1,V2,V3,V4	- control valves
1,2,3,4	- piping heat loss regions

2.2 System Operating Strategies - Space Heating

The operating strategy for the four space heating systems can be broken into three distinct steps: solar energy collection, space heating and domestic hot water (DHW) heating.

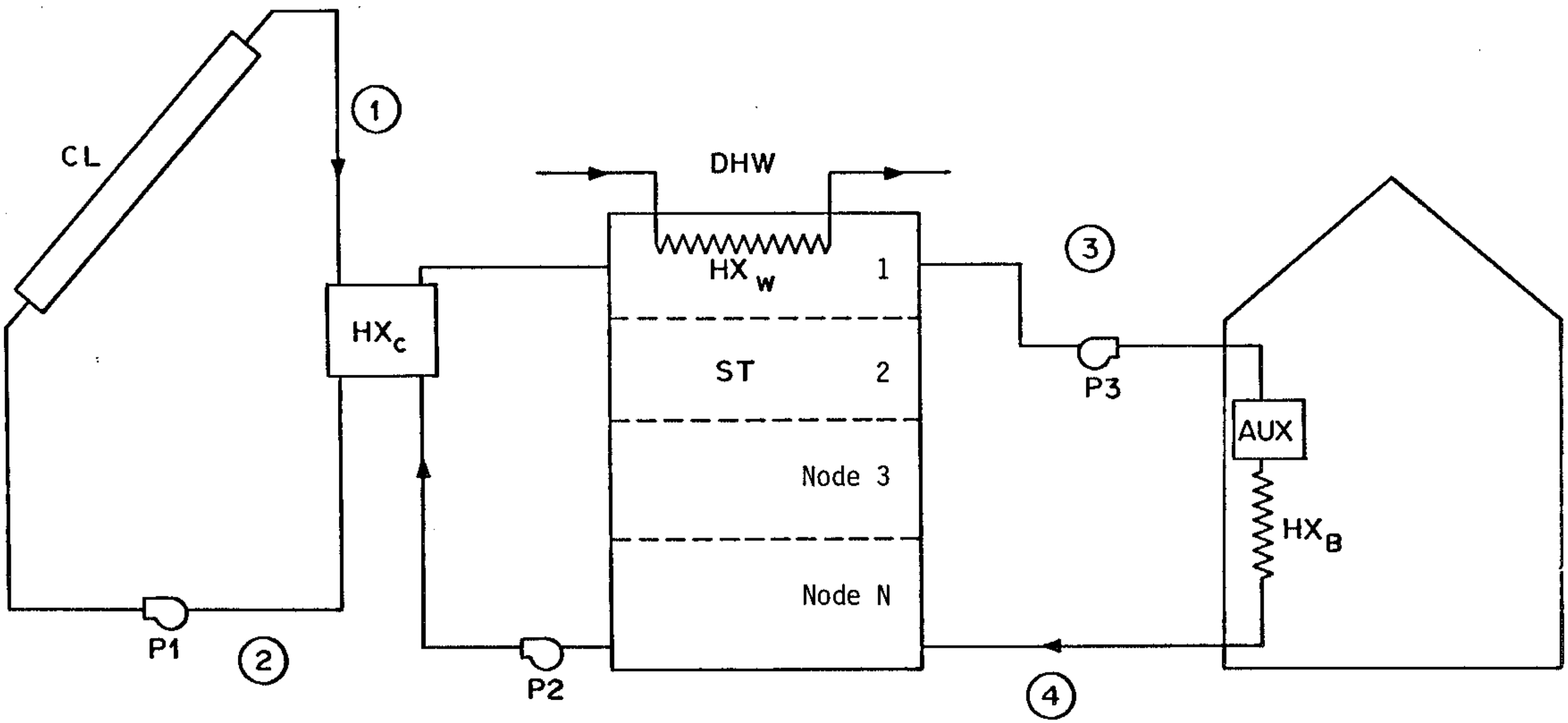


Figure 1: Solar Heating System Schematic - No Heat Pump - system type 0

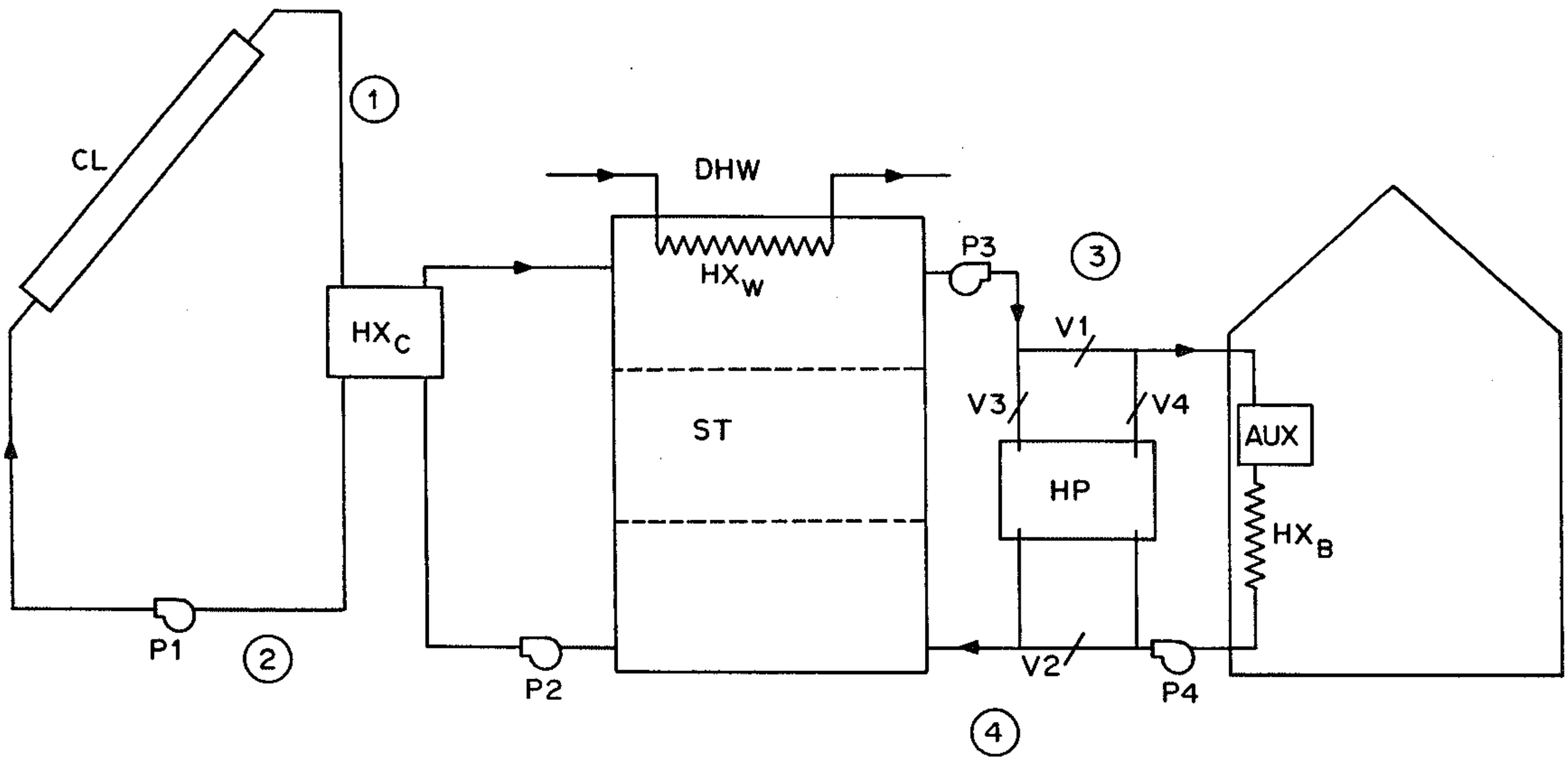


Figure 2: Solar Heating System Schematic - Heat Pump in Series with Solar Supply - system type 1

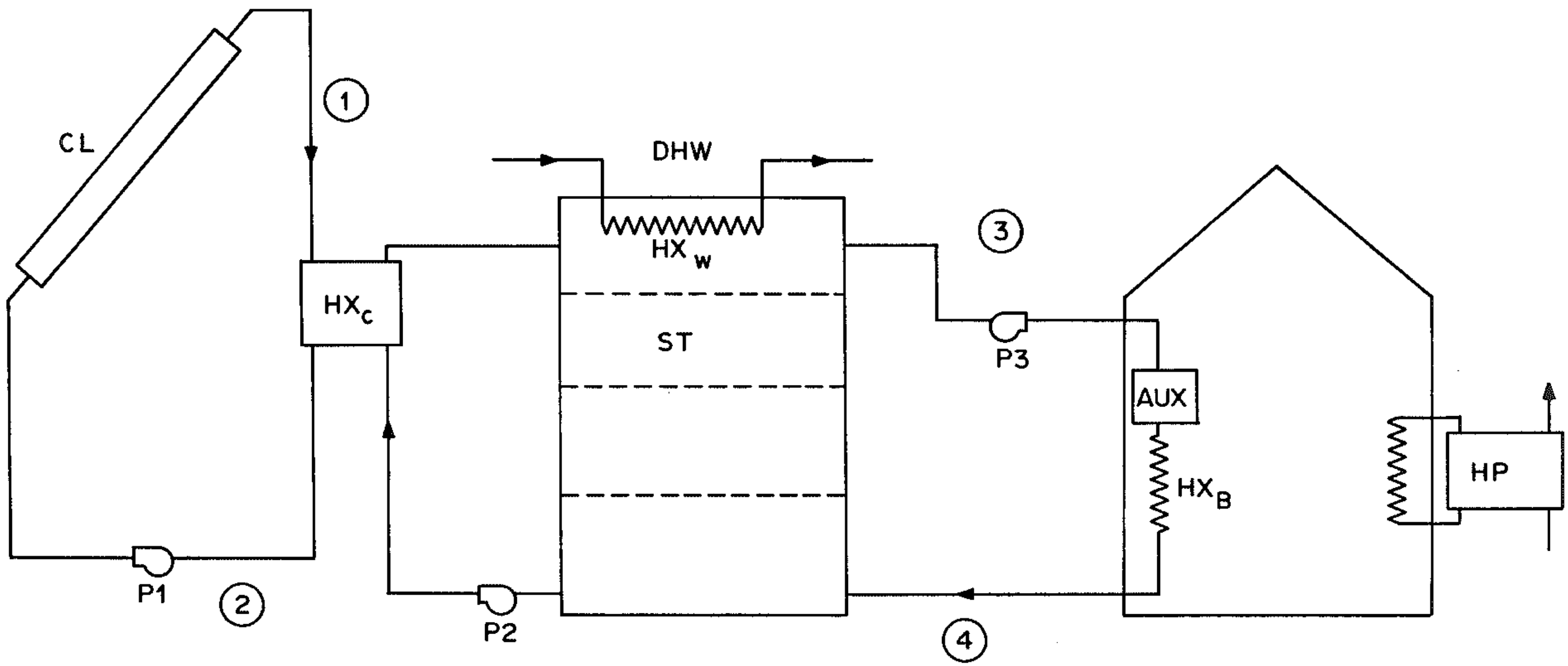


Figure 3: Solar Heating System Schematic - Heat Pump in Parallel with Solar Supply - system type 2

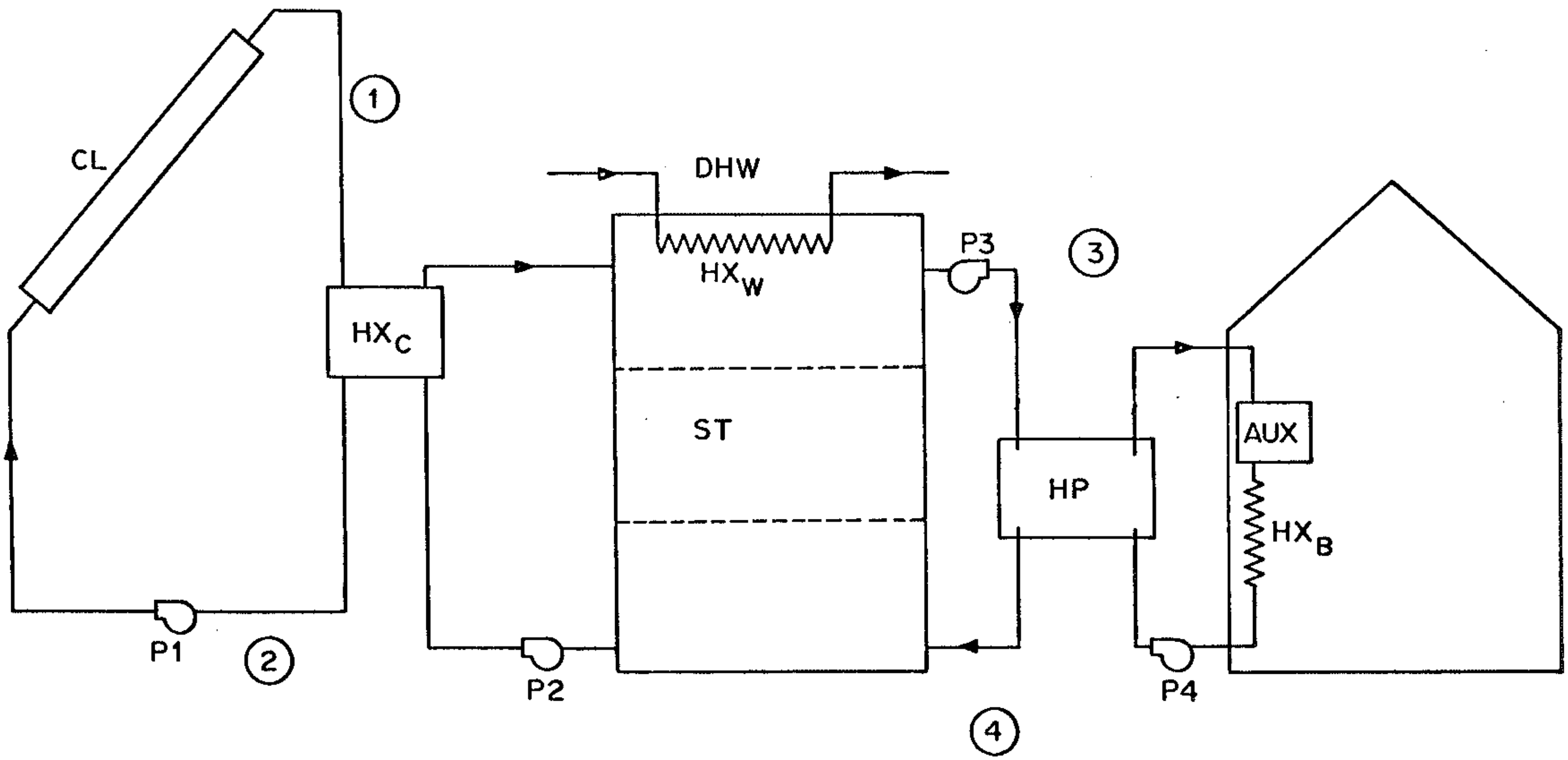


Figure 4: Solar Heating System Schematic - Heat Pump Supply Only - system type 3

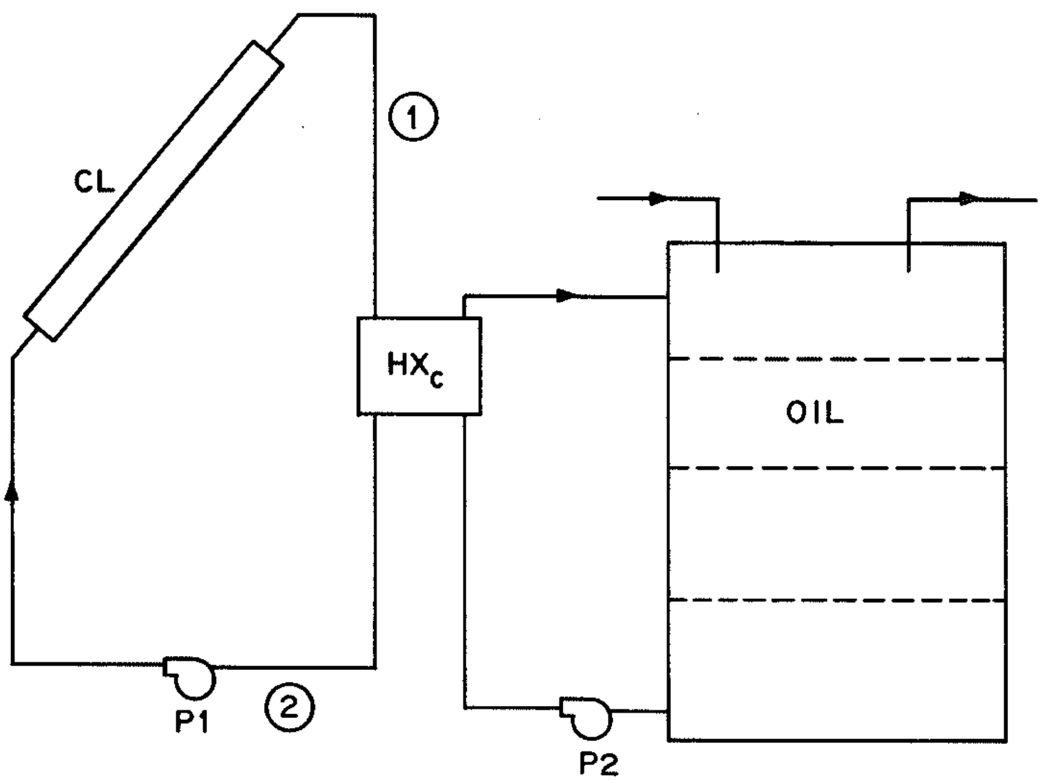


Figure 5: Oil Tank Heating System - system type 4

2.2.1 Solar Energy Collection Strategy

If the collector inlet fluid temperature is lower than the average collector plate temperature, solar energy can be collected and transferred to the storage tank. If the collector outlet temperature approaches the boiling point, the system will not operate. In this case, either the collectors would be drained or solar energy dumped through the pressure relief valve.

2.2.2 DHW Heating Strategy

Domestic hot water preheating is accomplished by passing city mains water through a heat exchanger contained in the top of the storage tank. The water, if not warmed to the desired water temperature, is heated by the conventional water heater. Note that the heat exchanger only operates when there is a water demand, i.e. there is no recirculation of the water. If the DHW heating load forms a large portion of the total heating load (greater than 20%) this model is not suitable and will not provide satisfactory results.

2.2.3 Space Heating Strategies

2.2.3.1 Space Heating Strategy - system type 0

No heat pump is used in this system. If the building requires heat, water from the storage tank is circulated through the building heat exchanger. This heat exchanger may be either hot water radiators or a water-to-air heat exchanger placed in the furnace return air duct. If the solar heat cannot meet the building demand, the auxiliary heater will make up the difference.

2.2.3.2 Space Heating Strategy - system type 1

This system is similar to system type 0 except that a heat pump is

added. The system first attempts to meet the heating demand from the solar heat (valves 1 and 2 open, valves 3 and 4 closed). If the solar heat cannot meet the demand, the solar heating system will not operate, and the heat pump will attempt to meet the load using the storage tank as the heat source (valves 3 and 4 open, valves 1 and 2 closed). If the heat pump cannot meet the demand, the auxiliary unit will make up the difference.

2.2.3.3 Space Heating Strategy - system type 2

This system operates in the same manner as system type 0 except that a heat pump is used as an auxiliary heater with the outside air as the heat source. If the solar heat cannot meet the demand, the heat pump will come on. Note that unlike system type 1, the heat pump and the solar heat can supply heat to the building at the same time. If the two heat sources cannot meet the heating demand the auxiliary unit will make up the difference.

2.2.3.4 Space Heating Strategy - system type 3

This system is similar to system type 1 except that solar heat cannot be delivered directly to the heating load the solar heat is always transferred to the load by means of the heat pump. This system will always have poorer performance than system type 1, however, it has a simpler layout and control strategy.

2.3 System Operating Strategies - Oil Tank Heating

This system differs from the previous four in that there is no space heating load. The heating requirement is to keep the oil above a minimum temperature (to prevent excessive viscosity) so that it can be pumped out when necessary.

The control strategy for heat collection is as described in Section 2.2. There is no DHW heating in this system. As will be described in Section 3.1

the DHW input parameters can be used to simulate draws of oil. There is no control strategy for space heating; the collected heat is continually added to the tank.

2.4 Tutorial Session

This section describes the use of the ENERPUB computer program. A full description of the input parameters is given in Section 3, and program output is described in Section 4.

When you have successfully signed on to your account and accessed the program, the computer will respond with the header.

```
************************************
*                                  *
*                                  *
*                                  *
*           ENERPUB - 1            *
*                                  *
*                                  *
*                                  *
*       PROGRAM VERSION 1.2        *
*  ENERMODAL ENGINEERING LIMITED   *
*            JULY 1982             *
*                                  *
*                                  *
*                                  *
************************************


DEVELOPED BY:

    ENERMODAL ENGINEERING LIMITED
    421 KING STREET NORTH
    WATERLOO, ONTARIO N2J 4E4
    (519) 884-6421


** LIQUID BASED SOLAR HEATING SYSTEM **
   WITH HEAT PUMP AND STRATIFIED TANK
```

The program will prompt the user for system characteristics concerning system type and whether the pipes or tank are buried.

```
  ENTER SOLAR SYSTEM TYPE....
     0 - STANDARD SOLAR SPACE HEATING (NO HEAT PUMP)
     1 - HEAT PUMP IN SERIES WITH SOLAR SUPPLY
     2 - HEAT PUMP IN PARALLEL WITH SOLAR SUPPLY
     3 - SOLAR ASSISTED HEAT PUMP ONLY
     4 - OIL TANK HEATING (NO HEAT PUMP)
0
  DO YOU WISH ECONOMIC ANALYSIS ? (Y/N)
y
  ARE THE PIPES OR TANK BURIED ? (Y/N)
```

The program will then print the message.

```
  INSTRUCTIONS....
     L - TO OBTAIN DATA LISTING
     R - TO RUN PROGRAM (WITH LISTING)
     C - TO CHANGE SYSTEM TYPE
     S - TO STOP SESSION, OR...
  TO CHANGE PARAMETER, TYPE CODE NUMBER
```

At this point the user has several choices of commands. If the user types...

"L" - the program will list all the input parameters with their present values.

"R" - the program will list all the parameters and start the simulation.

"C" - the system type and ground temperatures can be changed.

"S" - the computer session will be stopped.

a number - the program will ask for the new value of this parameter.

Normally the user will want to modify the input data. The code numbers are listed at the beginning of each line for each variable.

When the input data is correct, the user should type "R". The program will ask for the title of the run. The title has no effect on the program calculation, but merely serves as a method for distinguishing between computer runs. The title can be up to 72 characters in length on a single line.

```
  ENTER TITLE OF RUN
sample run
```

After the title has been entered, the simulation starts. The program will print the title and the input parameters.

```
SAMPLE RUN

                    ***  DATA INPUT LISTING  ***

* GENERAL SYSTEM DATA
  -------------------

    1. SIMULATION BEGINS IN YEAR...................  1970
    2. SIMULATION PERIOD (DAYS)....................   365
    3. DAY1 OF THE PERIOD (1-365)..................     1
    4. DETAILED PRINT-OUT (NO=0,YES=I-HR INTERVAL)      0
    5. STARTING HOUR OF PRINT INTERVAL (0,..,I)...      0
    6. TILTED ANGLE OF COLLECTOR.(DEGREES)........ 55.00
    7. COLLECTOR ORIENTATION (SOUTH=0.,DEGREES)...  0.00
```

```
* COLLECTOR DATA
  --------------

    10. GROSS COLLECTOR AREA (M2)..................100.00
    11. MAXIMUM COLLECTOR OUTLET TEMP.(C)..........   98.
    12. REQUIRED COLL-STORAGE TEMP. DIFFERENCE (C).   1.7
    13. POWER OF PUMPS 1&2 / COLLECTOR AREA (W/M2).    0.
    14. FLOW RATE * HT.CAPACITY (W/M2-C)...........   60.
    15. FR-TAU-ALPHA (ADJUSTED).................... 0.710
    16. FR-UL (ADJUSTED)  (W/M2-C)................. 3.910
    17. B0, COEFF. FOR INCIDENT ANGLE MODIFIER......-0.100
    18. COLLECTOR-STORAGE HX EFFECTIVENESS......... 1.000

* STORAGE DATA
  ------------

    20. STORAGE VOLUME/COLL.AREA  (M3/M2).......... 0.075
    21. STARTING TEMPERATURE (C)................... 20.00
    22. SURROUNDING TEMPERATURE (C)................  20.0
    23. TOP HEAT LOSS COEFF. (W/C).................  0.00
    24. SIDE HEAT LOSS COEFF. (W/C)................  0.00
    25. BOTTOM HEAT LOSS COEFF. (W/C)..............  0.00
    26. # OF STRATIFICATION TANK SEGMENTS..........     1
    27. SEG. # FOR COLLECTOR RETURN INTO TANK......     1
    28. SEG. # FOR BUILDING RETURN INTO TANK.......     1
    29. MINIMUM ALLOWABLE STORAGE TEMP.(C).........  4.00

* HEAT PUMP DATA
  --------------

    30. LOWER LIMIT OF EVAPORATOR TEMP.(C).........   0.0
    31. HIGHER LIMIT OF EVAPORATOR TEMP.(C)........  35.0
    32. COEFFICIENTS CQ, CP OF HEAT PUMP :
        5.000    448.000 15473.000
        0.000    103.000  5767.000

* BUILDING DATA
  -------------

    40. BUILDING UA COEFF. (W/C)...................1000.0
    41. POWER FOR HEATING FAN (W)..................    0.
    42. STORAGE-BUILDING HX EFFECTIVENESS.......... 0.700
    43. MIN.CAPACITANCE RATE OF LOAD HX.(W/C)...... 3000.
    44. DIRECT SOLAR GAIN FACTOR (M2)..............  0.00
    45. INDOOR DESIGN TEMPERATURE (C).............. 20.00
    46. INTERNAL HOURLY HEAT GAIN SCHEDULE (KJ)
           0.       0.       0.       0.       0.    1800.
        3600.    2700.    5400.    4500.    1800.    3600.
        4500.    3600.    2700.    2700.    1800.   16200.
        6300.    2700.    2700.    2700.    1800.    1800.
```

* WATER LOAD DATA

```
50. WATER  MAIN  TEMPERATURE  (C).............. 6.00
51. DESIRED HOT WATER TEMP.   (C).............. 40.00
52. DHW HX EFFECTIVENESS....................... 0.50
53. HOURLY HOT WATER SCHEDULE  (LITRES)
      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.
```

* PIPING DATA

```
60. PIPE HEAT LOSS COEFF - COL RETURN (W/C)....  0.00
61. SURROUNDING TEMPERATURE - COL RETURN (C)...  20.0
62. PIPE HEAT LOSS COEFF - COL SUPPLY (W/C)....  0.00
63. SURROUNDING TEMPERATURE - COL SUPPLY (C)...  20.0
64. PIPE HEAT LOSS COEFF - BDG SUPPLY (W/C)....  0.00
65. SURROUNDING TEMPERATURE - BDG SUPPLY (C)...  20.0
66. PIPE HEAT LOSS COEFF - BDG RETURN (W/C)....  0.00
67. SURROUNDING TEMPERATURE - BDG RETURN (C)...  20.0
```

* ECONOMIC DATA

```
70. SYSTEM LIFE (YEARS).........................     20
71. TERM OF LOAN (YEARS)........................     20
72. INTEREST RATE OF LOAN (%)...................10.000
73. RATE OF RETURN (DISCOUNT RATE) (%)..........10.000
74. FIXED COST OF SOLAR COMPONENTS ($)..........   830.
75. FIXED COST OF HEAT PUMP ($)................. 2180.
76. YEARLY MAINTENANCE COST OF SOLAR COMP.($/Y)    50.
77. YEARLY MAINTENANCE COST OF HP. ($/YR)......    50.
78. SALVAGE VALUE AT END OF PERIOD ($)..........    0.
79. UNIT COST OF COLLECTOR ($/M2)...............  230.
80. UNIT COST OF STORAGE ($/M3).................  122.
81. UNIT COST OF FUEL AT PRESENT ($/GJ).........10.000
82. % INFLATION RATE OF ENERGY:
      13.0    13.0    13.0    13.0    13.0
      10.0    10.0    10.0    10.0    10.0
      10.0    10.0    10.0    10.0    10.0
      10.0    10.0    10.0    10.0    10.0
```

If this is the first run, the solar radiation on the tilted collector must be calculated. To process the weather data, the program will ask the user for the latitude of the location.

```
  ENTER LATITUDE OF LOCATION (DEG.)
45.
    PROCESSING WEATHER DATA.....
```

If on successive runs the collector slope, collector azimuth or the first day of the period do not change, then the program will skip the weather data processing section.

After the weather data has been processed, the simulation starts. When the simulation is complete, the results are printed.

```
SIMULATION STARTS.....

                                      ******************************
* COLLECTOR AREA :   100.00 M2        *   ENERGY ANALYSIS SUMMARY   *
* STORAGE VOLUME :     7.50 M3        ******************************
```

M	SOLAR INCIDENT (GJ)	SOLAR COLLECT (GJ)	SOLAR DELIVER (GJ)	HT PUMP DELIVER (GJ)	SPACE HT LOAD (GJ)	AUX. SPACE HT (GJ)	WATER LOAD (GJ)	AUX. WATER HT (GJ)	PUMP POWER (GJ)
1	38.94	15.91	15.87	0.00	86.07	70.20	0.00	0.00	0.00
2	33.15	13.27	13.30	0.00	65.34	52.04	0.00	0.00	0.00
3	62.33	28.34	27.95	0.00	61.99	34.04	0.00	0.00	0.00
4	53.94	24.83	24.99	0.00	42.07	17.07	0.00	0.00	0.00
5	53.14	17.34	15.31	0.00	19.11	3.81	0.00	0.00	0.00
6	56.93	7.73	7.55	0.00	7.55	0.00	0.00	0.00	0.00
7	52.65	4.81	5.14	0.00	5.14	0.00	0.00	0.00	0.00
8	52.87	7.48	8.16	0.00	8.40	0.23	0.00	0.00	0.00
9	40.89	10.64	10.72	0.00	10.72	0.00	0.00	0.00	0.00
10	30.88	13.43	14.64	0.00	24.83	10.19	0.00	0.00	0.00
11	24.25	10.41	10.55	0.00	51.11	40.56	0.00	0.00	0.00
12	25.61	10.70	10.66	0.00	69.63	58.96	0.00	0.00	0.00
YR	525.6	164.9	164.8	0.0	451.9	287.1	0.0	0.0	0.0

```
**   TOTAL ENERGY INPUT TO ELECTRIC RESISTANCE REFERENCE SYSTEM
     OVER SIMULATION PERIOD, GJ :  451.449

**   ENERGY SAVING:   36.41 PERCENT

**   SEASONAL PERFORMANCE FACTOR :   1.57

**   MAX. HOURLY ENERGY INPUT (MJ):     179.447

**   ENERGY GAINED BY STORAGE TANK (GJ):  0.036

                         ***  ECONOMIC ANALYSIS  ***

**   PRESENT WORTH (AUXILIARY ENERGY INCL.)($):       92614.63
                   (AUXILIARY ENERGY NOT INCL.)($):   27776.34

**   LIFE-CYCLE UNIT COST (LUC), $/GJ :   10.257

**    SOLAR LUC , $/GJ    ,    8.450

 TO CHANGE PARAMETER, TYPE CODE NUMBER
s
```

The program will return with the prompt "TO CHANGE PARAMETER, TYPE CODE NUMBER". If the user is finished, type "S" to stop, otherwise modify the input parameters as necessary and re-run the program.

The simulation procedure for an oil tank heating system is shown below. The user should take note of the parameters that should be modified.

```
 ENTER SOLAR SYSTEM TYPE....
    0 - STANDARD SOLAR SPACE HEATING (NO HEAT PUMP)
    1 - HEAT PUMP IN SERIES WITH SOLAR SUPPLY
    2 - HEAT PUMP IN PARALLEL WITH SOLAR SUPPLY
    3 - SOLAR ASSISTED HEAT PUMP ONLY
    4 - OIL TANK HEATING (NO HEAT PUMP)
4
 DO YOU WISH ECONOMIC ANALYSIS ? (Y/N)
n
 ARE THE PIPES OR TANK BURIED ? (Y/N)
n
 INSTRUCTIONS....
```

```
      L - TO OBTAIN DATA LISTING
      R - TO RUN PROGRAM (WITH LISTING)
      C - TO CHANGE SYSTEM TYPE
      S - TO STOP SESSION, OR...
   TO CHANGE PARAMETER, TYPE CODE NUMBER
11
   ENTER NEW VALUE OF PARAMETER  11
55
   TO CHANGE PARAMETER, TYPE CODE NUMBER
51
   ENTER NEW VALUE OF PARAMETER  51
55
   TO CHANGE PARAMETER, TYPE CODE NUMBER
20
   ENTER NEW VALUE OF PARAMETER  20
5.
   TO CHANGE PARAMETER, TYPE CODE NUMBER
22
   ENTER NEW VALUE OF PARAMETER  22
-100
   TO CHANGE PARAMETER, TYPE CODE NUMBER
23
   ENTER NEW VALUE OF PARAMETER  23
300
   TO CHANGE PARAMETER, TYPE CODE NUMBER
24
   ENTER NEW VALUE OF PARAMETER  24
600
   TO CHANGE PARAMETER, TYPE CODE NUMBER
25
   ENTER NEW VALUE OF PARAMETER  25
300
   TO CHANGE PARAMETER, TYPE CODE NUMBER
53
   ENTER 24 VALUES OF HOT WATER LOAD (LITRES)
0 0 0 0 0 0 0 0 0 100 100 200 200 200 200 100 100 100 100 0 0 0 0 0
   TO CHANGE PARAMETER, TYPE CODE NUMBER
29
   ENTER NEW VALUE OF PARAMETER  29
28
   TO CHANGE PARAMETER, TYPE CODE NUMBER
21
   ENTER NEW VALUE OF PARAMETER  21
28
   TO CHANGE PARAMETER, TYPE CODE NUMBER
50
   ENTER NEW VALUE OF PARAMETER  50
28
   TO CHANGE PARAMETER, TYPE CODE NUMBER

r
   ENTER TITLE OF RUN
sample run #2
1
```

SAMPLE RUN #2

*** DATA INPUT LISTING ***

* GENERAL SYSTEM DATA

1.	SIMULATION BEGINS IN YEAR..................	1970
2.	SIMULATION PERIOD (DAYS)..................	365
3.	DAY1 OF THE PERIOD (1-365)................	1
4.	DETAILED PRINT-OUT (NO=0,YES=I-HR INTERVAL)	0
5.	STARTING HOUR OF PRINT INTERVAL (0,..,I)...	0
6.	TILTED ANGLE OF COLLECTOR.(DEGREES)........	55.00
7.	COLLECTOR ORIENTATION (SOUTH=0.,DEGREES)...	0.00

* COLLECTOR DATA

10.	GROSS COLLECTOR AREA (M2)..................	100.00
11.	MAXIMUM COLLECTOR OUTLET TEMP.(C)..........	55.
12.	REQUIRED COLL-STORAGE TEMP. DIFFERENCE (C).	1.70
13.	POWER OF PUMPS 1&2 / COLLECTOR AREA (W/M2).	0.
14.	FLOW RATE * HT.CAPACITY (W/M2-C)...........	60.
15.	FR-TAU-ALPHA (ADJUSTED)....................	0.710
16.	FR-UL (ADJUSTED) (W/M2-C)..................	3.91
17.	B0, COEFF. FOR INCIDENT ANGLE MODIFIER.....	-0.100
18.	COLLECTOR-STORAGE HX EFFECTIVENESS.........	1.000

* STORAGE DATA

20.	STORAGE VOLUME/COLL.AREA (M3/M2)...........	5.000
21.	STARTING TEMPERATURE (C)...................	28.00
22.	SURROUNDING TEMPERATURE (C)................	-100.0
23.	TOP HEAT LOSS COEFF. (W/C).................	300.00
24.	SIDE HEAT LOSS COEFF. (W/C)................	600.00
25.	BOTTOM HEAT LOSS COEFF. (W/C)..............	300.00
26.	# OF STRATIFICATION TANK SEGMENTS..........	1
27.	SEG. # FOR COLLECTOR RETURN INTO TANK......	1
28.	SEG. # FOR BUILDING RETURN INTO TANK.......	1
29.	MINIMUM ALLOWABLE STORAGE TEMP.(C).........	28.00

* BUILDING DATA

40.	BUILDING UA COEFF. (W/C)...................	0.0
41.	POWER FOR HEATING FAN (W)..................	0.
42.	STORAGE-BUILDING HX EFFECTIVENESS..........	0.700
43.	MIN.CAPACITANCE RATE OF LOAD HX.(W/C)......	3000.
44.	DIRECT SOLAR GAIN FACTOR (M2)..............	0.00
45.	INDOOR DESIGN TEMPERATURE (C)..............	20.00
46.	INTERNAL HOURLY HEAT GAIN SCHEDULE (KJ)	

0.	0.	0.	0.	0.	1800.
3600.	2700.	5400.	4500.	1800.	3600.
4500.	3600.	2700.	2700.	1800.	16200.
6300.	2700.	2700.	2700.	1800.	1800.

* WATER LOAD DATA

50. WATER MAIN TEMPERATURE (C)............... 28.00
51. DESIRED HOT WATER TEMP. (C)............... 55.00
52. DHW HX EFFECTIVENESS....................... 1.00
53. HOURLY HOT WATER SCHEDULE (LITRES)

0.	0.	0.	0.	0.	0.
0.	0.	0.	100.	100.	200.
200.	200.	200.	100.	100.	100.
100.	0.	0.	0.	0.	0.

* PIPING DATA

60. PIPE HEAT LOSS COEFF - COL RETURN (W/C).... 0.00
61. SURROUNDING TEMPERATURE - COL RETURN (C)... 20.0
62. PIPE HEAT LOSS COEFF - COL SUPPLY (W/C).... 0.00
63. SURROUNDING TEMPERATURE - COL SUPPLY (C)... 20.0
64. PIPE HEAT LOSS COEFF - BDG SUPPLY (W/C).... 0.00
65. SURROUNDING TEMPERATURE - BDG SUPPLY (C)... 20.0
66. PIPE HEAT LOSS COEFF - BDG RETURN (W/C).... 0.00
67. SURROUNDING TEMPERATURE - BDG RETURN (C)... 20.0

SIMULATION STARTS.....

* COLLECTOR AREA : 100.00 M2
* STORAGE VOLUME : 500.00 M3

****
* ENERGY ANALYSIS SUMMARY *
****

	M	SOLAR INCIDENT (GJ)	SOLAR COLLECT (GJ)	SOLAR DELIVER (GJ)	HT PUMP DELIVER (GJ)	SPACE HT LOAD (GJ)	AUX. SPACE HT (GJ)	WATER LOAD (GJ)	AUX. WATER HT (GJ)	PUMP POWER (GJ)
0	1	38.94	15.65	15.64	0.00	131.71	116.07	0.00	0.00	0.00
0	2	33.15	12.94	12.91	0.00	104.08	91.17	0.00	0.00	0.00
0	3	62.33	29.23	29.09	0.00	102.82	73.73	0.00	0.00	0.00
0	4	53.94	26.45	26.20	0.00	77.99	51.78	0.00	0.00	0.00
0	5	53.14	28.41	26.54	0.00	49.65	23.10	0.00	0.00	0.00
0	6	56.93	32.32	27.45	0.00	31.40	3.94	0.00	0.00	0.00
0	7	52.65	29.63	26.71	0.00	28.77	2.06	0.00	0.00	0.00
0	8	52.87	29.98	25.30	0.00	33.61	8.30	0.00	0.00	0.00
0	9	40.89	23.07	22.40	0.00	37.75	15.35	0.00	0.00	0.00
0	10	30.88	15.42	15.27	0.00	57.99	42.71	0.00	0.00	0.00
0	11	24.25	10.10	10.07	0.00	88.82	78.75	0.00	0.00	0.00
0	12	25.61	10.33	10.32	0.00	111.98	101.66	0.00	0.00	0.00
0	YR	525.6	263.6	247.9	0.0	856.6	608.6	0.0	0.0	0.0

```
**   TOTAL ENERGY INPUT TO ELECTRIC RESISTANCE REFERENCE SYSTEM
     OVER SIMULATION PERIOD, GJ :  855.771

**   ENERGY SAVING:   28.88 PERCENT

**   SEASONAL PERFORMANCE FACTOR :   1.41

**   MAX. HOURLY ENERGY INPUT (MJ):     254.883

**   ENERGY GAINED BY STORAGE TANK (GJ):  0.000

WARNING : HEATER IS REQUIRED IN STORAGE TO
  PREVENT DROPPING BELOW MINIMUM TEMPERATURE ! *
TO CHANGE PARAMETER, TYPE CODE NUMBER
S
```

* see page 55 for description

3. SYSTEM INPUT PARAMETERS

The following sections describe the parameters used in the ENERPUB computer program. The default values of these parameters are given in Section B. Make sure that input values are in the correct units.

3.1 Definition of Input Parameters

General System Parameters

1. SIMULATION BEGINS IN YEAR

   The year for which weather data is being used (See Section 3.2 for values).

2. SIMULATION PERIOD (DAYS)

   The number of days that the simulation will cover (typically 365 or less but minimum period is approximately 7 days).

3. DAY 1 OF THE PERIOD (1-365)

   The first day of the simulation period. January 1 is 1, September 1 is 244, etc. If this parameter is changed on successive runs the weather data will automatically be reprocessed.

4. DETAILED PRINT-OUT (NO = 0 YES = 1-HR INTERVAL)

   If this value is 0 monthly performance summaries will be printed. If this value is greater than 0, hourly performance summaries will be printed every time period specified. Thus if 6 were entered, a performance summary will be printed every 6 hours, for the 6th hour, and not the total of the 6hr. perio

5. STARTING HOUR OF PRINT INTERVAL (0,...1)

   The hour in which the detailed printing will start if parameter 4 is not 0.

6. TILTED ANGLE OF COLLECTOR (DEGREES)

   The angle that the collector is tilted from the horizontal. Range 0. to 90. If this parameter is changed on successive runs the weather data will automatically be reprocessed.

7. COLLECTOR ORIENTATION (SOUTH = 0, DEGREES)

The number of degrees that the collector is oriented off due south (east is positive, west is negative). Range -90. to 90. If this parameter is changed on successive runs the weather data will automatically be reprocessed.

Collector Parameters

10. GROSS COLLECTOR AREA (M2)

The gross collector area in square metres.

11. MAXIMUM COLLECTOR OUTLET TEMP. (C)

The maximum collector outlet temperature in degrees Celsius, typically slightly below water boiling point (98°C). For the oil tank heating system this would be equal to the maximum allowable oil temperature.

12. REQUIRED COL-STORAGE TEMP DIFF (C)

The required temperature difference between the bottom of the storage tank and the average collector temperature for the collector-storage loop to operate.

13. POWER OF PUMPS 1 AND 2/COLLECTOR AREA (W/M2)

The pump power required to transfer solar heat from the collector to the storage per unit collector area. This parameter should include the power of pumps 1 and 2. For a closed loop system, pump power is typically 10. W/m^2.

14. FLOW RATE * HT. CAPACITY (W/M2-C)

The flow rate times the heat capacity of the collector fluid per unit collector area. This value is typically 55 $W/m^2 \cdot C$, although the collector test value can be obtained from data sheets.

15. FR-TAU-ALPHA (ADJUSTED)

The $F_R\tau\alpha$ of the collector as determined from certified performance testing,

based on gross collector area, obtainable from data sheets. If parameter 14. is not equal to the test flow rate the $F_R\tau\alpha$ should be adjusted as given in Section 3.4.

16. FR-UL (W/M2-C)(ADJUSTED)

The F_RU_L of the collector as determined from certified performance testing, based on gross collector area, obtainable from data sheets. If parameter 14. is not equal to the test flow rate the F_RU_L should be adjusted as given in Section 3.4.

17. BO, INCIDENT ANGLE MODIFIER

Coefficient that reduces collector solar transmission for incident angles off the normal according to the formula $K = 1. + b_o(1./\cos\theta - 1.)$. The value for b_o is obtainable from the collector data sheets and is usually negative. If test results are not available use -0.10 for single glazed collectors and -0.175 for double glazed collectors.

18. COLLECTOR-STORAGE HX EFFECTIVENESS

The effectiveness of the heat exchanger between the collector and the storage, must be between 0 and 1. For drainback systems this parameter is 1.0.

Storage Parameters

20. STORAGE VOLUME/COLLECTOR AREA (M3/M2)

The ratio of storage volume to collector area, typically 0.075 for short term storage and 5.0 for annual or seasonal storage. The minimum storage size to ensure stability is approximately 0.04 m^3/m^2.

21. STARTING TEMPERATURE (C)

The starting temperature of the storage in degrees Celsius. This parameter is important for short simulation periods and annual storage systems because of the large thermal mass relative to the energy collected. A typical value for Jan. 1 is 20°C.

22. SURROUNDING TEMPERATURE (C)

The temperature of the air surrounding the storage, typically the building temperature for indoor storage. For outdoor storage units use a value of -100. This signals to the program that the storage heat loss is to the ambient air. For buried storage tanks use a value of -200. Note that monthly values of ground temperature would need to be entered at the start of the program. See Section 3.3 for typical ground temperatures.

23. TOP HEAT LOSS COEFF (W/C)

24. SIDE HEAT LOSS COEFF (W/C)

25. BOTTOM HEAT LOSS COEFF (W/C)

The top, side and bottom heat loss coefficients for the storage tank respectively, i.e. the surface area times the combined U value of the insulation and tank wall. The R value of the ground does not have to be included if the ground temperatures in Section 3.3 are used.

26. # OF STRATIFICATION TANK SEGMENTS

The number of equal segments the tank should be split into for the purposes of modelling. This parameter would equal 1 for a fully mixed tank. For multiple tank storage or a tall, slender tank this parameter should be greater than 1 (maximum value is 6). See Figure 1 pg. 3

27. SEG. # FOR COLLECTOR RETURN INTO TANK

The segment number of the tank into which the collector fluid returns, where segment number 1 is the top (typically 1).

28. SEG. # FOR BUILDING RETURN INTO TANK

The segment number of the tank into which the building fluid returns, typically the same value as parameter 26.

29. MINIMUM ALLOWABLE STORAGE TEMPERATURE (C)

The minimum allowable temperature of the storage tank water (or oil for oil tank heating). The default value is 4.°C. If the storage temperature drops below this value the program will print a warning and assumes an electric heater will bring the water up to the minimum temperature.

Heat Pump Parameters

30. LOWER LIMIT OF EVAPORATOR TEMP. (C)

The lowest temperature of the heat pump source (cold side) for which the heat pump will operate.

31. HIGHER LIMIT OF EVAPORATOR TEMP. (C)

The highest temperature of the heat pump source (cold side) for which the heat pump will operate.

32. COEFFICIENTS CQ, CP OF HEAT PUMP

Three coefficients of the heat supplied by the heat pump as a function of the source temperature and three coefficients of the heat consumed by the heat pump as a function of the source temperature in units of KJ/HR.

i.e. $\dot{Q}_{hp} = a_1T^2 + a_2T + a_3$

$$P_{hp} = b_1T^2 + b_2T + b_3$$

If these coefficients are not known the program will ask for data points on heat pump performance curve. The user will have to enter at least three values of source temperature (C), heat pump energy output (W) and heat pump energy input (W). With these data points the program will generate the required coefficients.

Building Parameters

40. BUILDING UA COEFF. (W/C)

The building heat loss coefficient as calculated according to the ASHRAE Handbook of Fundamentals including infiltration.

41. POWER FOR HEATING PUMPS (W)

The power necessary to operate pumps 3 and 4 and the building air circulation fan (if used).

42. STORAGE-BUILDING HX EFFECTIVENESS

The effectiveness of the heat exchanger between the storage and the building (HX_b), must be between 0 and 1.

43. MIN. CAPACITANCE RATE OF LOAD HX (W/C)

The minimum flow rate times heat capacity of the fluid on either side of the building heat exchanger. This value is usually one to three times the value of the building heat loss coefficient.

44. DIRECT SOLAR GAIN FACTOR (M2)

The area of south facing window used for passive solar heating. If the south facing window area is significantly greater than 5% of the floor area the passive solar contribution could be significantly overestimated and the program is not suitable.

45. INDOOR DESIGN TEMPERATURE (C)

The average indoor building temperature.

46. INTERNAL HOURLY HEAT GAIN SCHEDULE (KJ)

24 values of the hourly building internal heat gain from electric lights, appliances, people, etc.

Water Load Parameters

50. WATER MAIN TEMPERATURE (C)

The average water (or oil) supply temperature from the city mains or well. In general, this value is equal to the average ambient temperature over the year.

51. DESIRED HOT WATER TEMP. (C)

The desired hot water supply temperature (i.e. temperature setting of auxiliary water heater). For the oil tank heating system this parameter would be equal to the maximum allowable oil temperature (see Parameter 11).

52. DHW HX EFFECTIVENESS

The effectiveness of the DHW heat exchanger in the storage tank, must be between 0 and 1.

53. HOURLY HOT WATER SCHEDULE (LITRES)

24 values of the hourly hot water heating load (or oil removal rate) in litres.

Piping Parameters

60. PIPE HEAT LOSS COEFF-COL RETURN (W/C)

The heat loss per degree Celsius of the return piping from the collector (i.e. region 1) (see Section 3.5).

61. SURROUNDING TEMPERATURE-COL RETURN (C)

The air temperature surrounding the piping of parameter 60. Use a value of -100 for outdoor piping. A value of -200 should be used for buried piping.

62. PIPE HEAT LOSS COEFF-COL SUPPLY (W/C)

The heat loss per degree Celsius of the supply piping to the collector (i.e. region 2) (see Section 3.5).

63. SURROUNDING TEMPERATURE-COL SUPPLY (C)

The air temperature surrounding the piping of parameter 62. (-100 for outdoor piping, -200 for buried piping).

64. PIPE HEAT LOSS COEFF-BDG SUPPLY (W/C)

The heat loss per degree Celsius of the supply piping to the building (i.e. region 3) (see Section 3.5).

65. SURROUNDING TEMPERATURE-BDG SUPPLY (C)

The air temperature surrounding the piping of parameter 64. (-100 for outdoor piping, -200 for buried piping).

66. PIPE HEAT LOSS COEFF-BDG RETURN (C)

The heat loss per degree Celsius of the return piping from

the building (i.e. region 4) (see Section 3.5).

67. SURROUNDING TEMPERATURE-BDG RETURN (W/C)

The air temperature surrounding the piping of parameter 66. (-100 for outdoor piping, -200 for buried piping).

Economic Parameters

70. SYSTEM LIFE (YEARS)

The number of years for economic analysis, i.e. solar heating system lifetime, typically 20 years.

71. TERM OF LOAN (YEARS)

The number of years required to repay solar equipment loan.

72. INTEREST RATE OF LOAN (%)

The percent interest rate on parameter 71.

73. RATE OF RETURN (DISCOUNT RATE)(%)

The rate of return of best possible alternative investment in percent.

74. FIXED COST OF SOLAR COMP. ($)

The fixed installed cost of solar components not including heat pump.

75. FIXED COST OF HP. ($)

The fixed installed cost of heat pump.

76. YEARLY MAINTENANCE COST OF SOLAR COMP. ($/YR)

The yearly maintenance cost of solar components not including heat pump.

77. YEARLY MAINTENANCE COST OF HP.($/YR)

The yearly maintenance cost of heat pump.

78. SALVAGE VALUE AT END OF PERIOD ($)

The salvage value of solar heating system at the end of the period specified in parameter 70.

79. UNIT COST OF COLLECTOR ($/M2)

The installed cost of the system per square metre of collector not including the storage or the fixed costs of parameters 74. and 75.

80. UNIT COST OF STORAGE ($/M3)

The installed cost of the storage unit per cubic metre of storage.

81. UNIT COST OF FUEL AT PRESENT ($/GJ)

The cost of fuel being displaced including seasonal efficiency of the auxiliary heater. This value ranges from 5. to 15. depending on location and fuel used.

82. INFLATION RATE OF ENERGY (%)

20 values of projected yearly increase in fuel cost in percent.

3.2 Weather Data

At present there is weather data for 46 cities that can be used by the program. These cities are tabulated below. The solar radiation data as supplied by Atmospheric Environment Service is of two types: derived or measured. Measured data is as recorded by their monitoring equipment (with missing data estimated from the previous day's values). Derived data is predicted by using other meteorological data such as rainfall, cloud cover etc.

City	Province	Latitude (Deg.)	Year	Solar Rad. Derived/Measured
Victoria	B.C.	48.7	1971	D
Prince George	B.C.	53.9	1974	M
Vancouver	B.C.	49.2	1971	M
Summerland	B.C.	49.6	1971	D

Frobisher Bay	N.W.T.	63.8	1975	D
Resolute	N.W.T.	74.7	1971	M
Edmonton	Alta.	53.6	1971	M
Medicine Hat	Alta.	50.0	1971	D
Uranium City	Sask.	59.6	1971	D
Swift Current	Sask.	50.3	1971	D
Saskatoon	Sask.	52.2	1971	D
Churchill	Man.	58.8	1975	D
Brandon	Man.	49.9	1971	D
Winnipeg	Man.	49.9	1971	M
The Pas	Man.	53.8	1971	M
Thunder Bay	Ont.	48.4	1971	D
Sault Ste. Marie	Ont.	46.5	1971	D
Sudbury	Ont.	46.5	1971	D
Kapuskasing	Ont.	49.4	1966	M
Kingston	Ont.	44.2	1971	D
Muskoka	Ont.	45.0	1971	D
Windsor	Ont.	42.3	1971	D
London	Ont.	43.0	1971	D
Toronto	Ont.	43.7	1971	M
Ottawa	Ont.	45.4	1971	M
Montreal	Que.	45.5	1971	M
Sept. Iles	Que.	50.2	1974	M
Quebec	Que.	46.8	1971	D
Sherbrooke	Que.	45.4	1971	D
Riviere du Loop	Que.	47.8	1971	D
Bagotville	Que.	48.3	1971	D
Val D'Or	Que.	48.0	1971	D

MAP
Canadian Weather Stations

Fredericton	N.B.	45.9	1971	M
Charlo	N.B.	48.0	1971	D
Chatham	N.B.	47.0	1971	D
Moncton	N.B.	46.1	1971	D
St. John	N.B.	45.3	1971	D
Charlottetown	P.E.I.	46.3	1971	D
Truro	N.S.	45.4	1971	D
Halifax	N.S.	44.7	1971	M
Sydney	N.S.	46.2	1971	D
Yarmouth	N.S.	43.8	1971	D
St. John's	Nfld.	47.6	1971	M
Gander	Nfld.	49.0	1971	D
Stephenville	Nfld.	48.5	1971	D
Goose Bay	Nfld.	53.3	1971	M

3.3 Ground Temperature

Atmospheric Environment Service (A.E.S.) has been measuring the ground (soil) temperatures for many locations across Canada. Of the locations listed in Section 3.2, only 16 measure soil temperature. The soil temperatures at depths of 0.5 m and 1.5 m for these locations are given below. For further information on soil temperatures the user is referred to the A.E.S. publication "Soil Temperature Averages 1958-1978" by D.W. Phillips and D. Ashton, Report No. CLI3-79.

Prince George, B.C.

Soil temperature in °C at depths of 0.5 m and 1.5 m

J	F	M	A	M	J	J	A	S	O	N	D
1.3	1.0	0.8	1.5	6.0	10.8	13.3	14.1	12.2	8.6	4.6	2.4
4.2	3.3	2.7	2.4	3.5	6.0	8.5	10.3	10.6	9.7	7.7	5.7

Vancouver, B.C.

J	F	M	A	M	J	J	A	S	O	N	D
5.5	6.0	7.1	9.5	12.6	15.6	17.2	17.7	16.4	13.6	10.1	7.2
8.2	7.5	7.7	8.7	10.4	12.4	14.1	15.1	15.3	14.3	12.2	9.9

Summerland, B.C.

J	F	M	A	M	J	J	A	S	O	N	D
2.1	1.6	3.5	8.2	13.2	17.8	21.1	22.6	19.3	14.1	8.4	4.0
7.1	5.5	5.2	7.3	10.6	14.2	17.4	19.8	19.7	17.4	13.7	10.0

Resolute, N.W.T.

J	F	M	A	M	J	J	A	S	O	N	D
-16.9	-19.0	-20.0	-19.7	-17.0	- 9.0	-0.2	0.7	-1.7	-6.6	-10.7	-14.3
-14.8	-16.9	-18.1	-18.4	-16.9	-12.3	-5.5	-3.0	-3.1	-5.9	- 9.2	-12.4

Swift Current, Sask.

J	F	M	A	M	J	J	A	S	O	N	D
-0.6	-1.2	-0.6	1.1	6.3	11.8	14.8	15.4	12.7	8.2	3.8	0.9
2.0	1.1	0.8	0.9	2.9	7.0	10.1	11.6	11.4	9.1	6.5	3.8

Saskatoon, Sask.

J	F	M	A	M	J	J	A	S	O	N	D
-3.8	-4.0	-2.0	2.2	8.7	14.1	16.9	16.8	13.3	7.8	2.4	-1.6
2.1	1.1	0.6	1.0	4.1	8.4	11.5	12.7	12.2	9.9	6.8	4.0

Winnipeg, Man.

J	F	M	A	M	J	J	A	S	O	N	D
-1.4	-2.4	-1.5	-0.1	4.5	11.2	15.4	16.2	14.1	9.5	4.6	0.9
2.9	1.6	0.9	0.8	1.8	5.4	9.5	12.1	12.5	10.9	8.1	5.1

Kapuskasing, Ont.

J	F	M	A	M	J	J	A	S	O	N	D
0.9	0.5	0.3	0.7	5.6	12.2	15.6	15.8	12.7	7.9	3.6	1.6
3.8	3.1	2.6	2.4	3.4	7.2	10.5	12.2	12.0	9.9	7.3	5.1

Toronto, Ont.

J	F	M	A	M	J	J	A	S	O	N	D
1.3	0.4	0.9	3.6	9.3	14.5	17.5	18.7	16.3	11.1	7.5	3.6
6.6	5.4	4.5	4.9	8.1	11.8	14.6	16.5	16.3	14.3	11.9	9.2

Ottawa, Ont.

J	F	M	A	M	J	J	A	S	O	N	D
1.6	1.1	1.0	3.3	10.2	15.4	18.3	18.4	16.1	11.3	6.4	2.9
5.0	4.1	3.5	3.5	6.6	10.1	13.1	14.6	14.6	12.8	9.9	6.9

Val D'Or, Que.

J	F	M	A	M	J	J	A	S	O	N	D
0.4	0.1	0.0	0.6	6.9	13.2	16.4	16.3	13.0	7.9	3.6	1.4
2.8	2.2	1.6	1.3	3.3	8.1	11.6	13.2	12.4	9.5	6.5	4.0

Fredericton, N.B.

J	F	M	A	M	J	J	A	S	O	N	D
0.8	0.0	0.3	1.6	8.5	14.2	17.6	18.0	15.7	11.1	5.6	2.2
4.4	3.3	2.8	2.6	5.1	9.1	12.1	13.7	13.8	12.0	8.7	6.0

Charlottetown, P.E.I.

J	F	M	A	M	J	J	A	S	O	N	D
1.9	1.1	0.9	1.4	5.5	11.0	14.7	15.7	14.1	11.1	7.2	3.8
4.4	3.3	2.7	2.4	4.1	7.6	10.9	12.8	12.8	11.5	9.1	6.4

Truro, N.S.

J	F	M	A	M	J	J	A	S	O	N	D
1.9	1.1	0.9	1.4	5.5	11.0	14.7	15.7	14.1	11.1	7.2	3.8
4.4	3.3	2.7	2.4	4.1	7.6	10.9	12.8	12.8	9.1	9.1	6.4

St. John's, Nfld.

J	F	M	A	M	J	J	A	S	O	N	D
2.2	1.4	1.2	1.7	4.9	9.2	12.8	14.1	12.9	10.1	6.9	4.1
4.2	3.2	2.7	2.5	3.9	6.8	9.7	11.6	11.7	10.3	8.2	6.1

Goose, Nfld.

J	F	M	A	M	J	J	A	S	O	N	D
-0.3	-1.6	-1.3	-0.7	1.5	7.6	14.0	14.5	11.4	6.1	2.3	-0.2
1.8	0.1	0.8	0.8	0.6	4.5	9.4	11.7	11.2	8.2	5.0	2.8

3.4 Modification of Collector Test Data

The performance of a solar collector is dependent on the flow rate. If the collector flow rate for the proposed system is different from that used when the collector was tested the $F_R\tau\alpha$ and F_RU_L terms must be modified.

$$F_R\tau\alpha_{(adjusted)} = r \cdot F_R\tau\alpha_{(test)}$$

$$F_RU_{L\,(adjusted)} = r \cdot F_RU_{L(test)}$$

$$\text{where } r = \frac{\dot{m}\,Cp\,(1 - \exp[-AF'U_L/(\dot{m}\,Cp)]}{(\dot{m}\,Cp)_T(1 - \exp[-AF'U_L/(\dot{m}\,Cp)_T]}$$

$$F'U_L = \frac{(\dot{m}\,Cp)_T}{A}\ \ell n\,[1 - F_RU_{L\,(test)}\ A/(\dot{m}\,Cp)_T]$$

3.5 Calculation of Pipe Heat Loss Coefficient

The thermal conductance of pipe insulation is given by:

$$U = \frac{2\pi\,k\,L}{\ell n\ \frac{(d + 2t)}{d}} \qquad \text{in W/°C}$$

where d is the outside pipe diameter (mm)

t is the thickness of the insulation (mm)

L is the length of pipe (m)

k is the thermal conductivity of the insulation in W/m°C

$k_{fibreglass} \cong 0.0346$ W/m°C

$k_{polyurethane} \cong 0.0245$ W/m°C

4. DESCRIPTION OF PROGRAM OUTPUT

4.1 Thermal Analysis Results

The thermal analysis of the system is printed in monthly intervals with a yearly summary printed at the end. The results are an estimate of the system performance of a properly designed and installed system. The program cannot account for improperly insulated piping, pump failure or other system faults.

The output values are:

SOLAR INCIDENT (GJ)

Total solar radiation incident on the collector over the time period.

SOLAR COLLECT (GJ)

Solar energy transferred from the collector to the storage.

SOLAR DELIVERED (GJ)

Solar energy delivered to the space heating and hot water loads (not including heat pump contribution).

HT PUMP DELIVER (GJ)

Energy delivered by the heat pump to the space heating load.

SPACE HT LOAD (GJ)

Space heating load (i.e. auxiliary energy that would have to be supplied to meet the space heating load if there were no solar heating system).

AUX. SPACE HT (GJ)

Auxiliary energy required to meet the space heating load not met by the solar heating system.

WATER LOAD (GJ)

Energy required to meet the water heating load.

AUX. WATER HT (GJ)

Auxiliary energy required to meet the water heating load. The solar contribution to the water load is the difference between this value and the WATER LOAD.

PUMP POWER (GJ)

Total energy consumed by all pumps and fans in the system including the heat pump.

The "TOTAL ENERGY INPUT TO ELECTRIC RESISTANCE REFERENCE SYSTEM" is the total energy demand of a non-solar building. If a fuel other than electricity is used, this value should be divided by the seasonal furnace efficiency to determine the amount of fuel required. The "ENERGY SAVING" is the reduction in energy achieved by adding the solar heating system (i.e. percent solar). The "SEASONAL PERFORMANCE FACTOR" is another measure of energy savings. This factor is the number of times the non-solar building auxiliary energy consumption exceeds the solar building auxiliary energy consumption. The "MAX. HOURLY ENERGY INPUT (MJ)" is the maximum hourly energy input of the solar building. This value is useful for furnace sizing.

4.2 Economic Analysis

At the conclusion of the simulation year, the economic analysis is calculated and printed. The results of the economic analysis are extremely sensitive to the fuel excalation rate selected.

The first value of "PRESENT WORTH" is the total cost of installing and maintaining the solar heating system plus the cost of auxiliary energy over the system life at present prices. The second value is the cost of installing and maintaining the solar heating system over the system life at present prices.

The "LIFE-CYCLE UNIT COST" is the average price paid for building heating over the system life in present prices (includes solar heating system). That is, the first value of present worth divided by the total energy load of the building over the system life. The "SOLAR LUC" is the average price paid for the solar energy contribution over the system life in present dollars.

5. PROGRAM ALGORITHM

This section describes the thermodynamic models and equations used to simulate the solar heating system.

5.1 Overview of Program Operation

The basic assumption in the program is that for the purpose of thermal performance prediction, all variables, including solar radiation, ambient temperature and system energy flows can be considered constant for each hour.

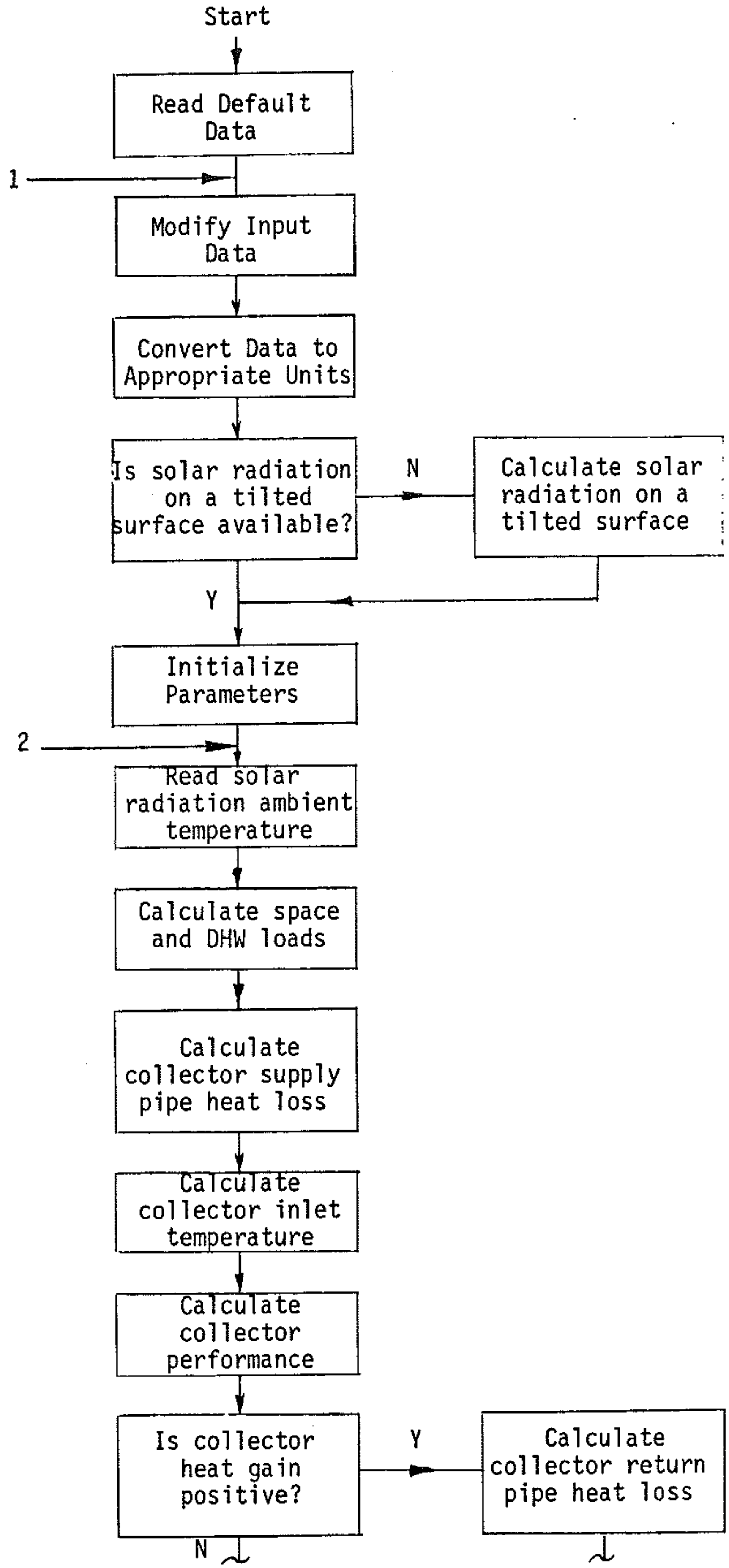
The calculation flow chart is shown in Figure 6. The first step in the program is the input from a data file of the default values of the input parameters. The user is then able to modify the input parameters as necessary. After all the input parameters are set, the user initiates the simulation (by typing "R"). If processed weather data is not available, the solar radiation on the tilted surface is calculated from the horizontal solar radiation contained in the weather data file. See Section 5.2 for a detailed description of the algorithm.

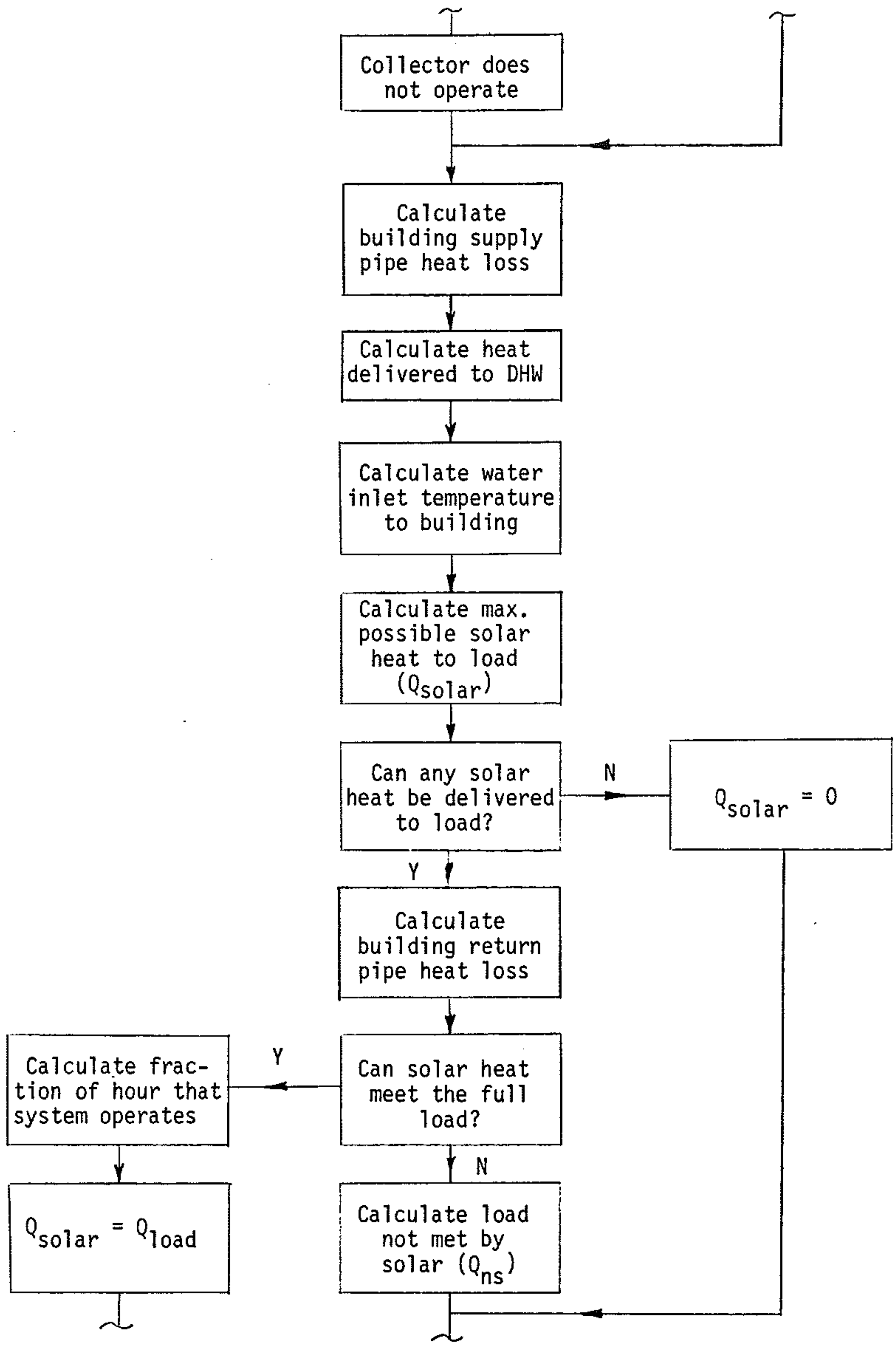
When the processing of the weather data is completed, the program begins the simulation. A new value of solar radiation and ambient temperature is read for each hour simulated. Based on the new values of ambient temperature, the space heating load and the water heating load (if necessary), are calculated. The space heating load is:

$$Q_{HT} = UA_b\,(T_{bg} - T_a) - IG$$

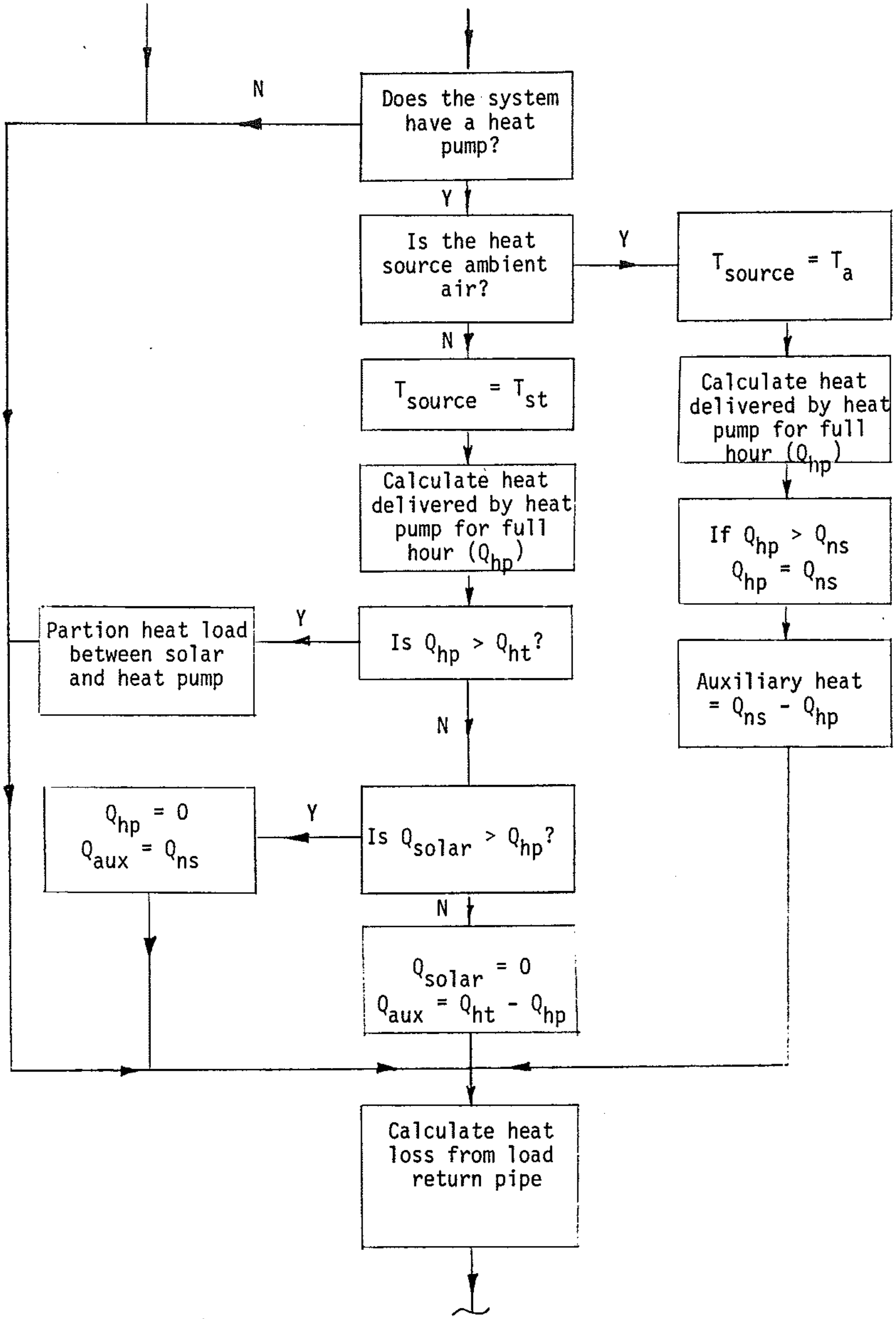
The next step is the calculation of the inlet fluid temperature to the collector. This temperature is equal to the temperature at the bottom of the storage tank minus the temperature drop due to pipe heat loss between the storage and collector inlet. See Section 5.3 for a detailed description of the algorithm for calculation of pipe heat loss. Knowing the collector fluid inlet temperature

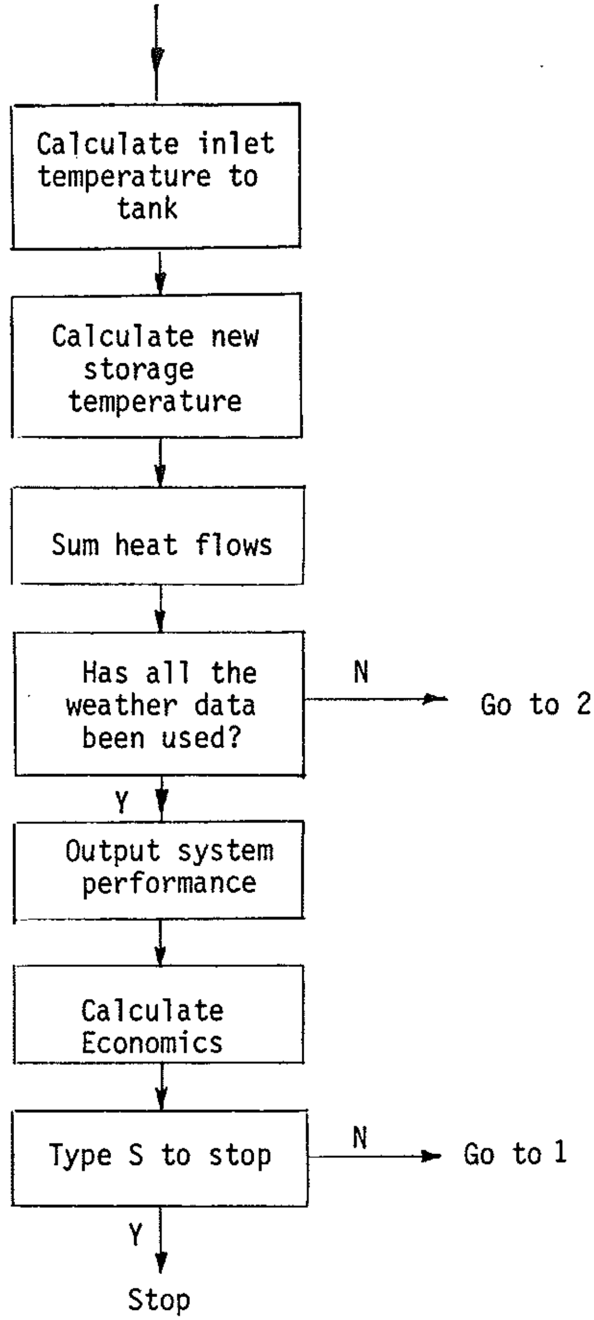
Figure 6: ENERPUB Flow Chart





Collector does not operate
Calculate building supply pipe heat loss
Calculate heat delivered to DHW
Calculate water inlet temperature to building
Calculate max. possible solar heat to load (Q_{solar})
Can any solar heat be delivered to load?
N
$Q_{solar} = 0$
Y
Calculate building return pipe heat loss
Can solar heat meet the full load?
Y
Calculate fraction of hour that system operates
$Q_{solar} = Q_{load}$
N
Calculate load not met by solar (Q_{ns})


Does the system have a heat pump?
N
Y
Is the heat source ambient air?
Y
$T_{source} = T_a$
N
$T_{source} = T_{st}$
Calculate heat delivered by heat pump for full hour (Q_{hp})
Calculate heat delivered by heat pump for full hour (Q_{hp})
If $Q_{hp} > Q_{ns}$ $Q_{hp} = Q_{ns}$
Partion heat load between solar and heat pump
Y
Is $Q_{hp} > Q_{ht}$?
Auxiliary heat $= Q_{ns} - Q_{hp}$
N
$Q_{hp} = 0$ $Q_{aux} = Q_{ns}$
Y
Is $Q_{solar} > Q_{hp}$?
N
$Q_{solar} = 0$ $Q_{aux} = Q_{ht} - Q_{hp}$
Calculate heat loss from load return pipe


Calculate inlet temperature to tank
Calculate new storage temperature
Sum heat flows
Has all the weather data been used?
N
Go to 2
Y
Output system performance
Calculate Economics
Type S to stop
N
Go to 1
Y
Stop

and the weather conditions, the collector performance can be determined. See Section 5.4 for a detailed description of the algorithm for collector performance. If the collector operates for the hour, the heat loss from the collector return piping and the fluid inlet temperature to the tank are calculated.

The next step is determination of the solar heat delivered to the load. The temperature of the supply water to the building can be calculated knowing the temperature of the top of the storage tank and the temperature drop due to pipe heat loss. The solar heat delivered to the water load is calculated by:

$$Q_{SDHW} = \varepsilon \cdot \frac{(T_{s1} - T_{mains})}{(T_{hot} - T_{mains})} \cdot Q_{DHW}$$

where ε is the effectiveness of the heat exchanger

T_{s1} is the temperature of the top of the storage tank

T_{mains} is the temperature of the city mains water

T_{hot} is the hot water set point temperature

If the solar heat can supply more heat than the building needs, the fraction of the hour that the system must operate to meet the demand is calculated.

If the solar heating system cannot meet the demand, the heat pump is used (if available). The energy output from the heat pump is calculated assuming that it operates for the full hour. See Section 5.5 for a description of the heat pump algorithm. If this value is greater than the heat load, then the solar energy and heat pump energy are partioned so that they operate for the full hour and exactly meet the demand. If the heat pump and solar heating system cannot meet the demand, auxiliary energy is assumed to make up the difference.

If the solar heating system supplied heat to the building, the heat loss from the return piping is calculated. The temperature of the load return water can be calculated knowing the pipe heat loss and heat delivered to the load.

At the conclusion of the hour, the new temperature(s) of the storage tank are calculated based on the collector and load flow rates. Section 5.6 contains a detailed description of the stratified storage tank algorithm.

Finally, the hourly heat flows are summed for the simulation period and the monthly and yearly totals displayed on the printer. The economic analysis is performed at this point. See Section 5.7 for a detailed description of the economic analysis algorithm.

5.2 Algorithm to Process Weather Data

Most Canadian weather stations measure only total solar radiation on a horizontal surface. Most solar collectors, however, are tilted toward the sun to increase the incident solar radiation. The program determines hourly values of total solar radiation (beam, diffuse and reflected) on a tilted surface and stores the values in a scratch file. The algorithm for converting horizontal solar radiation to tilted solar radiation is similar to the method used in Duffie and Beckman (1).

In order to estimate the solar radiation on a tilted surface it is necessary to split the total measured horizontal solar radiation into its two components: beam and diffuse. It is possible to estimate the amount of diffuse solar radiation from the ratio of the measured solar radiation to the extraterrestrial solar radiation. If this ratio is low then the solar radiation must be mostly diffuse; if this ratio is high the solar radiation must be mostly beam.

When the beam and diffuse solar radiation components are known, standard geometric relations can be used to estimate the solar radiation components on a tilted surface. When estimating solar radiation on a tilted surface a third component is introduced: reflected radiation. Reflected radiation can be estimated from the beam radiation and the ground albedo or reflectivity.

The program equations and execution procedure are given below.

At the start of each day the solar constant and the earth's solar declination are calculated. The solar constant is given by

$$S_c = 4871.0\ (1. + 0.33 \cos (2\pi N / 365)) \qquad \text{in KJ/(hr}\cdot\text{m}^2)$$

where N is the day number (Jan 1 is 1).

The earth's declination is given by

$$\delta = \frac{23.45 * 2\pi}{360} *\sin\left(\frac{2\pi\,(284 + N)}{360 \quad *365}\right) \qquad \text{(in radians)}$$

These values are assumed constant for each day. All other calculations are made on an hourly basis.

The first step is to read the measured weather values from the data file. For each hour the weather data file contains six values in the following order.

1) month number (1-12)
2) day number (1-31)
3) hour number (1-24)
4) ground reflectivity
5) solar radiation on a horizontal surface (in Watts/m²)
6) ambient temperature (in °C)

The extraterrestrial solar radiation on a horizontal surface is calculated by

$$H_{ex} = S_c \cdot \cos(\theta_z)$$

where $\cos(\theta_z)$ is cosine of the zenith angle (angle between the beam and the vertical)

$$\cos(\theta_z) = \cos(\phi)\cos(\delta)\cos\ w + \sin\phi\ \sin\delta$$

ϕ is the latitude of the location

w is the hour angle.

The diffuse solar radiation (H_d) can be estimated using a correlation by Orgill and Hollands (2).

$$H_d = 0.1769 \cdot H \qquad \text{if } 0.75 < K_T$$

$$H_d = (1.55699 - 1.84013 \cdot K_T) \cdot H \qquad \text{if } 0.35 \leq K_T \leq 0.75$$

$$H_d = (1. - 0.248857 \cdot K_T) \cdot H \qquad \text{if } 0.0 \leq K_T \leq 0.35$$

where H is the measured hourly solar radiation

K_T is the ratio of measured solar radiation to the extraterrestrial solar radiation
$= H / H_{ex}$

The beam radiation (H_b) is simply the total measured solar radiation minus the diffuse radiation.

$$H_b = H - H_d$$

The next step is to calculate the ratio of beam radiation on the tilted surface to that on the horizontal surface (R_b).

$$R_b = \cos(\theta_T) / \cos(\theta_z)$$

where $\cos(\theta_T)$ is the cosine of the angle of incidence of beam radiation, between the beam and the normal to the surface.

$$\cos(\theta_T) = \sin(\delta)\sin(\phi)\cos(s) - \cos(\delta)\cos(\phi)\cos(s)\cos(w) + \cos(\delta)\sin(\phi)\sin(s)\cos(\gamma)\cos(w)\cos(\delta)\sin(s)\sin(\gamma)\sin(w)$$

γ is the azimuth angle measured from south (east is positive, west is negative)

Thus, the beam solar radiation on the tilted surface is

$$H_{bT} = R_b H_b$$

The diffuse solar radiation component on the tilted surface is estimated using the radiation view factor from the collector to the sky with correction factors for non-uniform distribution of diffuse radiation.

The correction factors for anisotropic diffuse radiation are taken from Temps and Coulson (3) and Klucher (4). The resulting equation is

$$H_{dT} = \left(\frac{1 + \cos(s)}{2}\right)(1 + F\sin^3(s/2))(1 + F\cos^2(\theta_T) \cdot \sin^3(\theta_z))H_d$$

where $F = 1 - (H_d/H)^2$

The reflected solar radiation on the tilted surface (H_r) is

$$H_r = \left(\frac{1 - \cos(s)}{2}\right) \rho H$$

where ρ is the ground reflectivity

The total solar radiation on the tilted surface (H_T) is the sum of the beam diffuse and reflected solar radiation components.

Hourly values of total solar radiation on a tilted surface, ambient temperature, day number and hour number are written to the scratch file. When all the data has been processed and written to the scratch file, the file is rewound to be ready for the system simulation.

5.3 Algorithm for Calculation of Pipe Heat Loss

The method of calculating pipe heat loss is the same for all of the pipes. The heat loss is based on the difference between the average fluid temperature and the surrounding temperature.

$$Q_{loss} = UA_{pipe} (T_{fm} - T_{env}) \tag{1}$$

where UA_{pipe} is the pipe heat loss coefficient

T_{env} is the temperature of the environment surrounding the pipe. This is either a constant value, hourly ambient temperature or monthly ground temperature (depending on the value of parameters 61, 63, 65, 67)

T_{fm} is the average temperature of the fluid

$= (T_{fin} + T_{fout})/2$

The outlet fluid temperature can be calculated from the pipe heat loss and the mass flow rate.

$$T_{fo} = T_{fi} - Q_{loss}/(\dot{m}\ C_p) \tag{2}$$

Equations (1) and (2) are dependent on one another, that is they both contain the same two unknowns Q_{loss} and T_{fo}. By combining the equations the unknowns can be solved exactly.

$$Q_{loss} = UA_{pipe}(T_{fin} - T_{env})/(1 + \frac{UA_{pipe})}{2\ \dot{m}\ C_p}$$

5.4 Algorithm for Solar Collector Performance

The instantaneous performance of solar collectors is represented by the standard Hottel-Whillier-Bliss model of $F_R\tau\alpha$ and F_RU_L. The program assumes that both these collector characteristics are independent of temperature and solar radiation.

If a collector-to-storage heat exchanger is used, the $F_R\tau\alpha$ and F_RU_L are modified according to the method of DeWinter (5).

$$F_R\tau\alpha' = F_R\tau\alpha \cdot E_X$$

$$F_RU_L' = F_RU_L \cdot E_X$$

where $E_X = \dot{m}_c C_p \,/\, (\dot{m}\, C_p + F_RU_L * (1 - E_{hx}) / E_{hx})$

and the ' on a value means that it includes the effect of the heat exchanger.

For each hour, the reduction in solar transmission of the collector for non-normal angles of incidence is calculated. This reduction (K) is given by:

$$K = 1. + b_o\left(\frac{1}{\cos(\theta)} - 1.\right)$$

where b_o is the incident angle modifier

θ is the incident angle of the beam radiation on the collector

To determine if the collector will operate for a given hour, the stagnation temperature (T_c) is calculated.

$$T_c = T_a + H_T \cdot K \cdot F_R\tau\alpha' \,/\, F_RU_L'$$

If T_c is greater than the inlet temperature, the collector is assumed to operate for the full hour. If T_c is less than the inlet temperature the collector does not operate. The heat collected by the collector is

$$Q_c = F_RU_L' \cdot \text{Area} \cdot (T_c - T_{ci})$$

The collector outlet temperature is

$$T_{co} = T_{ci} + Q_c \,/\, (\dot{m}_c C_p)$$

5.5 Algorithm for Heat Pump

The energy delivered by the heat pump (Q_{hp}) is estimated by using a correlation between energy output and the source or heat pump evaporator temperature (T_e). The energy consumed by the heat pump (P_{hp}) is estimated in a similar manner.

$$Q_{hp} = a_1 T_e^{\,2} + a_2 T_e + a_3$$

$$P_{hp} + b_1 T_e^{\,2} + b_2 T_e + b_3$$

where a_1, a_2, a_3 and b_1, b_2, b_3 are correlation coefficients

The correlation coefficients can be estimated from the heat pump performance curve, available from the heat pump manufacturer. Alternatively, performance data points can be entered into the program and the program will generate the coefficients using a least squares analysis.

The heat pump operation is assumed to be steady state for each one-hour time step of the simulation. This implies that the temperature of the heat source, whether the solar storage tank or ambient air, is constant over the hour or the fraction of the hour needed to meet the load.

The coefficient of performance (COP) of the heat pump is defined as:

$$COP = Q_{hp}/P_{hp}$$

A heat pump can only operate within specific ranges of temperatures. If the evaporator temperature is outside this range, the internal control system will prevent the heat pump from operating. To simulate this operation, the program checks at the beginning of the hour to see if the source temperature is between the minimum and maximum values. If it is outside of this range, it is assumed that the heat pump does not supply any heat for that hour.

5.6 Algorithm for Stratified Storage Tank

Water storage tanks in solar systems will exhibit some temperature stratification. The magnitude of the stratification depends on system flow rates and temperatures. The model used in the program is as recommended by Klein (6). This model is similar to, yet more flexible than, the model given in Duffie and Beckman (1).

The tank is modelled as a series of horizontal nodes. A mass and energy balance is performed on the nodes for each simulated hour. The water entering the tank (from either the load or the collector) is assumed to rise or fall to the node closest in temperature. If water is flowing from the load and the collector, the fluid streams are assumed fully mixed before they enter each segment. The energy balance on the tank also takes into account the heat lost by each node to the environment and the heat transferred from the storage top node to the domestic hot water by means of the DHW heat exchanger.

A heat balance on a storage node gives:

$$T_{si}' = T_{si} + [\alpha_i \dot{m}_c C_p \ (T_{co} - T_{si}) + \beta_i \dot{m}_L C_p \ (T_{lo} - T_{si}) - Q_{loss} + Q_{up} + Q_{down}] \ / \ (m_i C_p)$$

where T_{si} is the temperature of the node i at the beginning of the hour

T_{si}' is the temperature of the node i at the end of the hour

$\dot{m}_c$, $\dot{m}_L$ are the hourly mass flows from the collector and load to the storage

C_p is the specific heat of water

m_i is the mass of the water in node i

Q_{loss} is the amount of heat lost to the environment by conduction out the storage walls

Q_{up}, Q_{down} is the amount of heat transferred into the node by flow coming up or going down

α, β are control functions that define the node(s) where the fluid effectively returns

The control functions are given by:

if $r_c \leqq i \leqq S_c$ or $S_c \leqq i \leqq r_c$

then $\alpha_i = 1 / (|r_c - S_c| + 1)$

otherwise $\alpha_i = 0$

if $r_L \leqq i \leqq S_L$ or $S_L \leqq i \leqq r_L$

then $\beta_i = 1 / (|r_L - S_L| + 1)$

otherwise $\beta_i = 0$

where r_c is the node number where the collector fluid returns

r_L is the node number where the load fluid returns

S_c is the node number to which the collector return fluid is closest in temperature

S_L is the node number to which the load return fluid is closest in temperature

The quantity Q_{down} is given by:

for $\gamma_i > 0$

$$Q_{down} = \gamma_i \, (Ts_{i-1} - Ts_i)$$

where $\gamma_i = \dot{m}_c C_p \sum_{j=1}^{i-1} \alpha_j - \dot{m}_L C_p \sum_{j=i}^{N} \beta_j$

otherwise $Q_{down} = 0$

The quantity Q_{up} is given by

for $\gamma_{i+1} < 0$

$$Q_{up} = \gamma_{i+1} \, (Ts_i - Ts_{i+1})$$

After the temperatures have been updated, two checks are made in the program. The first check is for storage temperature instability. If the temperature of a node is greater than the one above it, it is assumed that density differences will cause perfect mixing of these nodes. Because all the nodes have equal thermal capacity, the new temperature of the nodes is the arithmatic average of the mixing nodes. The second check is on the minimum allowable temperature. If the temperature of any of the nodes goes below the minimum allowable temperature, it is assumed that an auxiliary heater comes on. Because the heater is most probably placed in the bottom of the tank, the heated water will rise and cause a fully mixed tank. If the heater has to come on a warning flag is printed.

5.7 Algorithm for Economic Analysis

The algorithm for economic analysis is standard and is given in many economic textbooks. Two economic indicators are calculated: (i) present worth of solar savings (with and without auxiliary energy) (ii) life-cycle unit cost of energy (with and without solar heating system).

In the present worth analysis, all future payments, whether for fuel or bank loans, are discounted back to present. The present worth of yearly expenditures for fuel and maintenance are:

$$P.W._f = \sum_{i=1}^{N} C_{fuel} \ (1 + i)^N / (1 + r)^N$$

$$P.W._m = \sum_{i=1}^{N} C_{main} / (1 + r)^N$$

where C_{fuel}, C_{main} are the first year costs for fuel and maintenance respectively

i is the fuel inflation rate

r is rate of return on the best alternative investment

The present worth of the loan repayments is

$$P.W._{ss} = C_{ss} \frac{l \ (1 + l)^L \ ((1 + r)^L - 1.)}{((1 + l)^L - 1.) \ r(1 + r)^L}$$

where C_{ss} is the total cost of the solar system

l is the interest on the loan

L is the loan period in years

The salvage value is discounted back to present by:

$$P.W._{sal} = C_{sal} / \ (1 + r)^N$$

Thus, the present worths of the solar investment with and without fuel costs are:

$$P.W._{solar_1} = P.W._{ss} + P.W._m - P.W._{sal}$$

$$P.W._{solar_2} = P.W._{ss} + P.W._{m} + P.W._{f} - P.W._{sal}$$

These are the values printed in the economic analysis. The life-cycle unit costs can be found from the present worth. The life-cycle unit cost is

$$LUC = P.W._{solar_1} / E_{tot}$$

where E_{tot} is the total heating load over the system life

The solar life-cycle unit cost is

$$SLUC = P.W._{solar_2} / (E_{tot} \cdot F_s)$$

where F_s is the fraction of the heating load met by the solar heating system

6. PROGRAM STRUCTURE

The purpose of this section is to describe the program structure. Only those individuals interested in modifying the program need read this section.

The program flow chart is shown in Figure 7. The program consists of a mainline and 16 subroutines:

i) MAINLINE - main program for file unit number allocation and calling of subroutines.

ii) PRINT 1 - subroutine to print title page at start of program.

iii) PRINT 2 - subroutine to print hourly energy analysis summaries.

iv) INPUT - interactive subroutine for user input of data and printing of input data. This subroutine reads the default data from a data file.

v) WEATH - subroutine for converting measured horizontal solar radiation to the tilted surface. The weather data is read from a data file and the processed data is written to a new file.

vi) SYSTEM - subroutine to initialize system parameters and sum the system energy flows. At the conclusion of the simulation the yearly results are printed.

vii) LOGIC - subroutine to call the component subroutines depending on energy flows.

viii) CLECTR - subroutine to calculate collector performance.

ix) LOAD - subroutine to calculate water and building heat loads and the solar contribution to these loads.

x) HTPUMP - subroutine to calculate heat pump performance.

xi) PIPE - subroutine to calculate heat loss from a pipe (used for all four pipes).

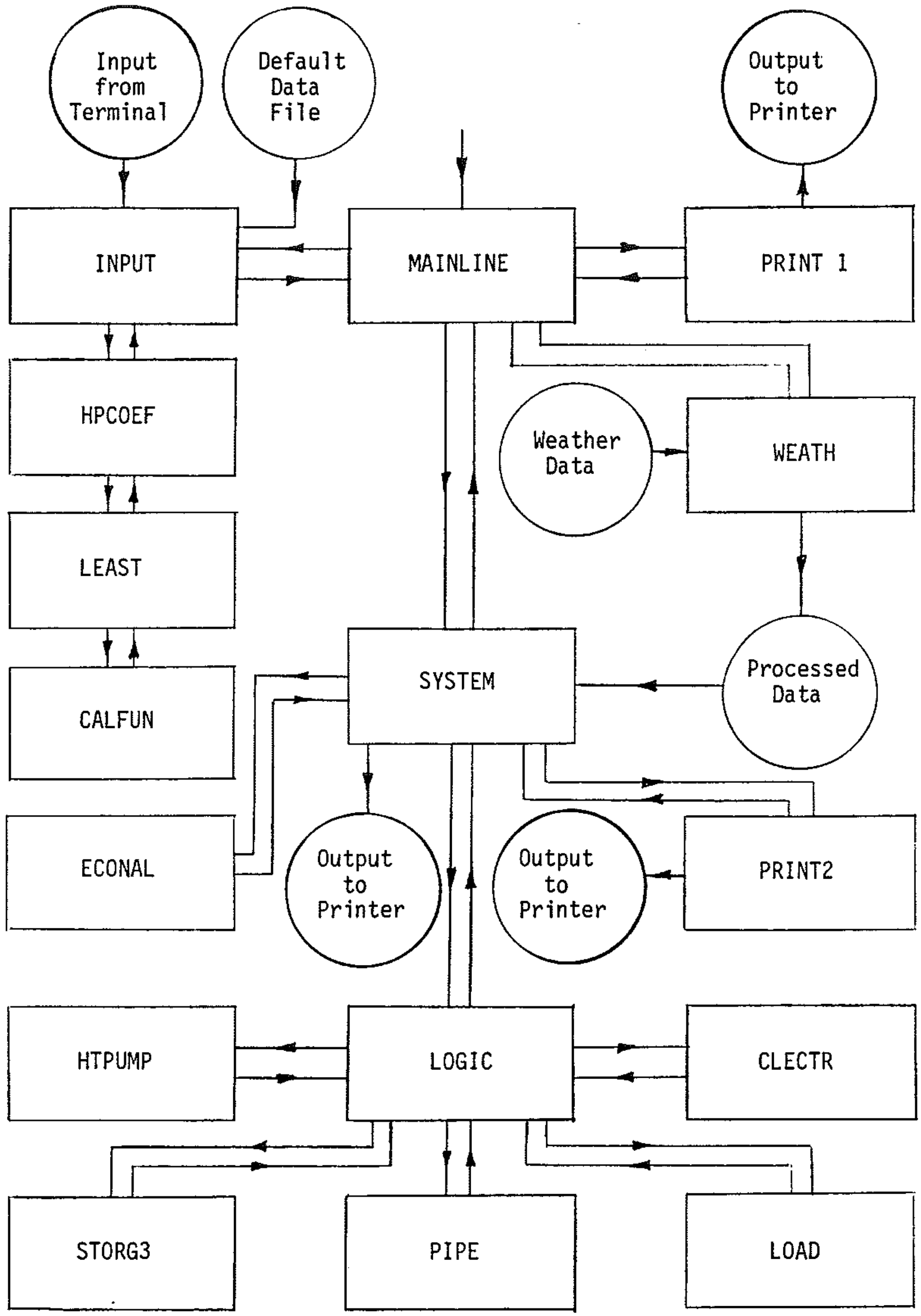
xii) STORG3 - subroutine to calculate the new temperature(s) of the storage tank at the end of the hour.

xiii) ECONAL - subroutine to perform economic analysis.

xiv) TGRD - subroutine to determine monthly ground temperature.

xv) HPCOEF - subroutine to determine heat pump power input and output characteristics.

Figure 7: ENERPUB Program Structure



xvi) CALFUN - subroutine that contains general form of heat pump power equation.

xvii) LEAST - subroutine to perform least squares analysis on heat pump power data points.

Four file definitions must be made before the program can be run:

Terminal/Printer - (Unit 12) is the device for data input and program output

Default Data - (Unit 10) is the file that contains default data for the system parameters.

Weather Data - (Unit 8) is the file that contains the TRNSYS compatible weather data. The data must be written in the format (2X,I2,2X,I2,2X,I2,F3.1,I3,F6.1) and contain month number, day number, hour number, ground reflectivity, ambient temperature (°C) and solar radiation on a horizontal surface (W/m^2).

Processed Data - (Unit 9) is the file that is created by the program containing the solar radiation on the tilted surface, and the ambient temperature.

7. REFERENCES

1) Duffie and Beckman, Solar Engineering of Thermal Processes, John Wiley and Sons, New York, 1980.

2) Orgill, J.F. and Hollands, K.G.T., Solar Energy, Vol. 19, No. 2, "Correlation Equation for Hourly Diffuse Radiation on a Horizontal Surface".

3) Temps, R.C. and Coulson, K.L., Solar Energy, Vol. 19, No. 2, "Solar Radiation Incident upon Slopes of Different Orientation".

4) Klucher, T.M., Solar Energy, Vol. 23, No. 2, "Evaluation of Models to Predict Insulation on Tilted Surfaces".

5) deWinter, F., Solar Energy, Vol. 17, "Heat Exchanger Penalties in Double-Loop Solar Water Heating Systems".

6) Klein, S.A., A Design Procedure for Solar Heating Systems, Ph.D. Thesis, University of Wisconsin-Madison, 1976.

8. INPUT DATA WORKSHEET

ENERPUB Commands

```
    L - TO OBTAIN DATA LISTING
    R - TO RUN PROGRAM (WITH LISTING)
    C - TO CHANGE SYSTEM TYPE
    S - TO STOP SESSION, OR...
TO CHANGE PARAMETER, TYPE CODE NUMBER
```

ENERPUB Input Data With Default Values

```
* GENERAL SYSTEM DATA
  -------------------

   1. SIMULATION BEGINS IN YEAR..................  1970  ____________
   2. SIMULATION PERIOD (DAYS)...................   365  ____________
   3. DAY1 OF THE PERIOD (1-365).................     1  ____________
   4. DETAILED PRINT-OUT (NO=0,YES=I-HR INTERVAL)     0  ____________
   5. STARTING HOUR OF PRINT INTERVAL (0,...,I)...     0  ____________
   6. TILTED ANGLE OF COLLECTOR.(DEGREES)........ 55.00  ____________
   7. COLLECTOR ORIENTATION (SOUTH=0.,DEGREES)...  0.00  ____________

* COLLECTOR DATA
  --------------

  10. COLLECTOR AREA (M2).......................100.00  ____________
  11. MAXIMUM OUTLET TEMP.(C)....................   98.  ____________
  12. DIFFERENTIAL TEMPERATURE (C)...............  1.70  ____________
  13. PUMP POWER / COLLECTOR AREA (W/M2).........    0.  ____________
  14. FLOW RATE * HT.CAPACITY (W/M2-C)...........   60.  ____________
  15. FR-TAU-ALPHA............................... 0.710  ____________
  16. FR-UL   (W/M2-C)...........................  3.91  ____________
  17. B0, COEFF. FOR INCIDENT ANGLE MODIFIER.....-0.100  ____________
  18. COLLECTOR-STORAGE HX EFFECTIVENESS......... 1.000  ____________

* STORAGE DATA
  ------------

  20. STORAGE VOLUME/COLL.AREA  (M3/M2).......... 0.075  ____________
  21. STARTING TEMPERATURE (C)................... 20.00  ____________
  22. SURROUNDING TEMPERATURE (C)................  20.0  ____________
  23. TOP HEAT LOSS COEFF. (W/C).................  0.00  ____________
  24. SIDE HEAT LOSS COEFF. (W/C)................  0.00  ____________
  25. BOTTOM HEAT LOSS COEFF. (W/C)..............  0.00  ____________
  26. # OF STRATIFICATION TANK SEGMENTS..........     1  ____________
  27. SEG. # FOR COLLECTOR RETURN INTO TANK......     1  ____________
  28. SEG. # FOR BUILDING RETURN INTO TANK.......     1  ____________
  29. MINIMUM ALLOWABLE STORAGE TEMP.(C).........  4.00  ____________
```

* HEAT PUMP DATA

30. LOWER LIMIT OF EVAPORATOR TEMP.(C).......... 0.0 ____________
31. HIGHER LIMIT OF EVAPORATOR TEMP.(C)......... 35.0 ____________
32. COEFFICIENTS CQ, CP OF HEAT PUMP : ____________

* BUILDING DATA

40. BUILDING UA COEFF. (W/C)...................1000.0 ____________
41. POWER FOR HEATING FAN (W).................. 0. ____________
42. STORAGE-BUILDING HX EFFECTIVENESS........... 0.700 ____________
43. MIN.CAPACITANCE RATE OF LOAD HX.(W/C)...... 3000. ____________
44. DIRECT SOLAR GAIN FACTOR (M2)............... 0.00 ____________
45. INDOOR DESIGN TEMPERATURE (C)............... 20.00 ____________
46. INTERNAL HOURLY HEAT GAIN SCHEDULE (KJ)

0.	0.	0.	0.	0.	1800.
3600.	2700.	5400.	4500.	1800.	3600.
4500.	3600.	2700.	2700.	1800.	16200.
6300.	2700.	2700.	2700.	1800.	1800.

* WATER LOAD DATA

50. WATER MAIN TEMPERATURE (C)............... 6.00 ____________
51. DESIRED HOT WATER TEMP. (C)............... 40.00 ____________
52. DHW HX EFFECTIVENESS........................ 0.50 ____________
53. HOURLY HOT WATER SCHEDULE (LITRES)

0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

* PIPING DATA

60. PIPE HEAT LOSS COEFF - COL RETURN (W/C).... 0.00 ____________
61. SURROUNDING TEMPERATURE - COL RETURN (C)... 20.0 ____________
62. PIPE HEAT LOSS COEFF - COL SUPPLY (W/C).... 0.00 ____________
63. SURROUNDING TEMPERATURE - COL SUPPLY (C)... 20.0 ____________
64. PIPE HEAT LOSS COEFF - BDG SUPPLY (W/C).... 0.00 ____________
65. SURROUNDING TEMPERATURE - BDG SUPPLY (C)... 20.0 ____________
66. PIPE HEAT LOSS COEFF - BDG RETURN (W/C).... 0.00 ____________
67. SURROUNDING TEMPERATURE - BDG RETURN (C)... 20.0 ____________

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* ECONOMIC DATA
  -------------

    70. SYSTEM LIFE (YEARS)........................      20
    71. TERM OF LOAN (YEARS).......................      20
    72. INTEREST RATE OF LOAN......................   0.100
    73. RATE OF RETURN (DISCOUNT RATE).............   0.100
    74. FIXED COST OF SOLAR COMPONENTS ($).........    830.
    75. FIXED COST OF HEAT PUMP ($)................   2180.
    76. YEARLY MAINTENANCE COST OF SOLAR COMP.($/Y)     50.
    77. YEARLY MAINTENANCE COST OF HP. ($/YR)......     50.
    78. SALVAGE VALUE AT END OF PERIOD ($).........      0.
    79. UNIT COST OF COLLECTOR ($/M2)..............    230.
    80. UNIT COST OF STORAGE ($/M3)................    122.
    81. UNIT COST OF FUEL AT PRESENT ($/GJ)........10.000
    82. INFLATION RATE OF ENERGY :
        0.130   0.130   0.130   0.130   0.130
        0.100   0.100   0.100   0.100   0.100
        0.100   0.100   0.100   0.100   0.100
        0.100   0.100   0.100   0.100   0.100
```

9. NOMENCLATURE

a	heat pump coefficients
A	collector area (m^2)
b	heat pump coefficients
b_o	incident angle modifier
C_{fuel}	first year fuel cost (\$/yr)
C_{main}	first year maintenance cost (\$/yr)
COP	coefficient of performance
C_p	specific heat (KJ/(kg$\cdot$°C)
C_{sal}	salvage value (\$)
C_{ss}	total cost of the solar system (\$)
DHW	domestic hot water load (litres)
E_{tot}	total heating load over system life (GJ)
E_x	heat exchanger factor
F_R	collector heat removal factor
$F_R\tau\alpha$	collector transmission-absorption coefficient
F_RU_L	collector heat loss coefficient (W/($m^2\cdot$°C)
F_S	fraction solar
H	measured hourly solar radiation (KJ/(hr$\cdot m^2$)
H_b	beam hourly solar radiation (KJ/(hr$\cdot m^2$)
H_{bT}	beam hourly solar radiation on a tilted surface (KJ/(hr$\cdot m^2$)
H_d	diffuse hourly solar radiation (KJ/(hr$\cdot m^2$)
H_{dT}	diffuse hourly solar radiation on a tilted surface (KJ/(hr$\cdot m^2$)
H_{ex}	extraterrestrial hourly solar radiation (KJ/(hr$\cdot m^2$)
HP	heat pump
H_r	reflected hourly solar radiation (KJ/(hr$\cdot m^2$)

HX	heat exchanger
i	fuel inflation rate
IG	internal heat gain (KJ)
K_T	clearness index
l	loan interest rate
L	loan period (years)
LUC	life-cycle unit cost
$\dot{m}$	mass flow rate (kg/hr)
$\dot{m}_c$	mass flow rate through the collector (kg/hr)
m_i	mass of water in node i (kg)
$\dot{m}_L$	mass flow rate to the load (kg/hr)
N	day number of the year
P	pump
P_{hp}	heat pump energy input (KJ/hr)
$P.W._f$	present worth of fuel expenditures ($)
$P.W._m$	present worth of maintenance expenditures ($)
$P.W._{sal}$	present worth of salvage value ($)
$P.W._{solar}$	present worth of solar investment ($)
$P.W._{ss}$	present worth of loan repayments ($)
Q_{aux}	auxiliary heat requirement (KJ/hr)
Q_c	solar energy collected by collector (KJ/hr)
Q_{DHW}	domestic hot water heating load heat transfer (KJ/hr)
Q_{down}	heat storage nodes (KJ/hr)
Q_{hp}	heat pump energy output (KJ/hr)
Q_{HT}	space heating load (KJ/hr)
Q_{load}	space heating load (KJ/hr)

Q_{loss}	heat loss from pipe or tank (KJ/hr)
Q_{ns}	heat load not met by solar (KJ/hr)
Q_{SDHW}	solar contribution to DHW load (KJ/hr)
Q_{solar}	maximum possible solar contribution (KJ/hr)
Q_{up}	heat transfer between storage nodes (KJ/hr)
r	rate of return
r_c	node number where the collector fluid returns
r_L	node number where the load fluid returns
R_b	ratio of beam radiation on tilted surface to horizontal surface
S_c	node number to which the collector return fluid is closest in temperature
S_L	node number to which the load return fluid is closest in temperature
SLUC	solar life-cycle unit cost
Ta	ambient temperature (°C)
T_{bg}	building temperature (°C)
T_c	collector stagnation temperature (°C)
T_{ci}	collector inlet temperature (°C)
T_{co}	collector outlet temperature (°C)
T_{env}	temperature of the environment surrounding the pipe (°C)
T_{fin}	collector fluid inlet temperature (°C)
T_{fout}	collector fluid outlet temperature (°C)
T_{hot}	hot water set point temperature (°C)
T_{mains}	city mains water temperature (°C)
T_{s1}	temperature of the top of the storage tank (°C)
T_{si}	temperature of storage node i (°C)
T_{source}	heat pump source temperature (°C)
T_{st}	storage temperature (°C)

UA_b	building heat loss coefficient (W/°C or KJ/(hr°C)
UA_{pipe}	pipe heat loss coefficient (W/°C or KJ/(hr°C)
UL	collector heat loss coefficient (W/(m²°C)
α	solar absorptivity
γ	azimuth angle
π	3.14159
ρ	density (kg/m³)
α_i	stratified storage constant
γ_i	stratified storage constant
β_i	stratified storage constant
θ	incident angle

ENERPUB MANUAL: ERRATA NOTICE

The following corrections apply to the ENERPUB Users Manual, November 1982:

Page 42	"Partion heat load" should read "Partition heat load"
Page 44, line 20	"partioned" should read "partitioned"
Page 46, line 25	S_c should read SC
Page 47, line 16	S_c should read SC
Page 66	Q_{down} - the amount of heat transferred into the storage node when flow goes down
Page 67	Q_{up} - the amount of heat transferred into the storage node when flow goes up
Page 67	SC - solar constant